Growth of Aquatic Plants in Southern Ontario Impoundments in Relation to Phosphorus, Nitrogen and Other Factors

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GROWTH OF AQUATIC PLANTS

IN

SOUTHERN ONTARIO IMPOUNDMENTS IN RELATION

TO PHOSPHORUS, NITROGEN AND OTHER FACTORS

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ABSTRACT

In 1969-70 species composition and standing crops of macrophytes and phytoplankton were studied in both natural and man-made impoundments, located within a 90 km radius of Toronto.

The total hardness of the epilimnial waters ranged from 53 to 307 ppm and the pH from 6.9 to 8.4. Total alkalinities ranged from 60 to 223 ppm. Total and soluble phosphorus concentrations varied between 0.010 to 0.065 and 0.002 to 0.019 ppm, respectively. Nitrates averaged from less than 0.01 to 1.91 ppm and nitrites from 0.001 to 0.070 ppm. Surface concentrations of Kjeldahl nitrogen ranged from 0.24 to 1.37 ppm and ammonia from 0.010 to 0.634 ppm. Stratification was strongest in the deep kettle lakes and flooded sand pits and was weakest in those shallow impoundments having appreciable flushing throughout the year.

The plankton of the shallow impoundments with extensive stands of macrophytes consisted chiefly of diatoms, flagellates and green algae. In contrast, blooms of blue-green algae were characteristic of the kettle lakes and the deepest pond, where macrophyte growth was restricted due to light penetration.

Significant correlations were found between the concentrations of phosphorus and iron in the plant tissues and in the epilimnial waters but none were found for nitrogen or manganese. There were no significant

correlations between the concentrations of these elements in the plants and in the sediments.

When the quantities of minerals contained in the samples of macrophytes were prorated per hectare, it was evident that these plants removed large quantities of nutrients from their environment. For example, a stand of elodea in one pond contained 89 Kg/ha N and 7 Kg/ha P at the time of sampling. The implications of these findings in aquatic weed control and nutrient removal are emphasized.

INTRODUCTION

This study is part of a detailed investigation of the ecology of small impoundments in southern Ontario, carried out jointly by the Ministry of Natural Resources and the Ministry of the Environment to obtain information required for the effective management of multipurpose recreational ponds and storage reservoirs. Although the study is confined to waters located within a 90 km. radius of Toronto, the waters varied widely with respect to morphometry, water supply, chemical and physical characteristics.

One of the most important aspects which will be considered in these continuing investigations is the relationship between rooted aquatic plants and the fish populations. A prerequisite to this type of evaluation is a detailed understanding of the physical, chemical and biological characteristics of the impoundments. An earlier publication dealt with the growth and distribution of aquatic macrophytes relative to water transparency and general level of water fertility (McCombie and Wile, 1971). The present report examines this distribution and growth more closely, particularly in regard to specific chemical parameters such as alkalinity, pH, phosphorus and nitrogen.

The relationships between morphometry, water supply, temperature and water chemistry of the impoundments are also discussed. Particular attention is given to the relationship between thermal and chemical stratification and the impact of seasonal changes on the growth and distribution of aquatic plants.

Owing to possible competition between macrophytes and phytoplankton for available nutrients, the latter flora were sampled routinely to assess their distribution and abundance.

DESCRIPTION OF THE IMPOUNDMENTS AND STUDY AREA

Location, dimensions and water supply of the impoundments.

The impoundments are located within a 90 km. radius of Toronto on five river systems which arise in various sections of the Oak Ridges Moraine and empty into Lake Ontario (Figure 1). Both natural and man-made impoundments are included, the former being of Pleistocene origin and the latter from 10-50 years old. Many of the impoundments are situated on headwaters while others are located some distance downstream. The kettle lakes 01 and 37 and the sand pit 35 are landlocked.

The impoundments differ widely in morphometry (Table 1). The kettle lakes, with the exception of impoundment 37, and the two flooded sand pits are very deep (6 to 17m) relative to their surface areas (2 to 14 ha). Impoundment 37 is very shallow relative to its area and might be more properly classified as a marsh. The ponds formed by headwater or downstream dams are shallow to moderately deep (2 to 5m) with the exception of impoundment 03 which as a maximum depth of 8m.

The impoundments also differ widely with respect to water supply. In all cases surface runoff is a major component but this varies with the size of the watershed. It is particularly important in downstream ponds having large watersheds (e.g. 17, 18 and 31). There is also a marked seasonal variation, runoff being greatest during spring snowmelt and least during summer drought. This accounts for the considerable variation in discharge for individual ponds. Heavy rains produce temporary increases in runoff and discharge.

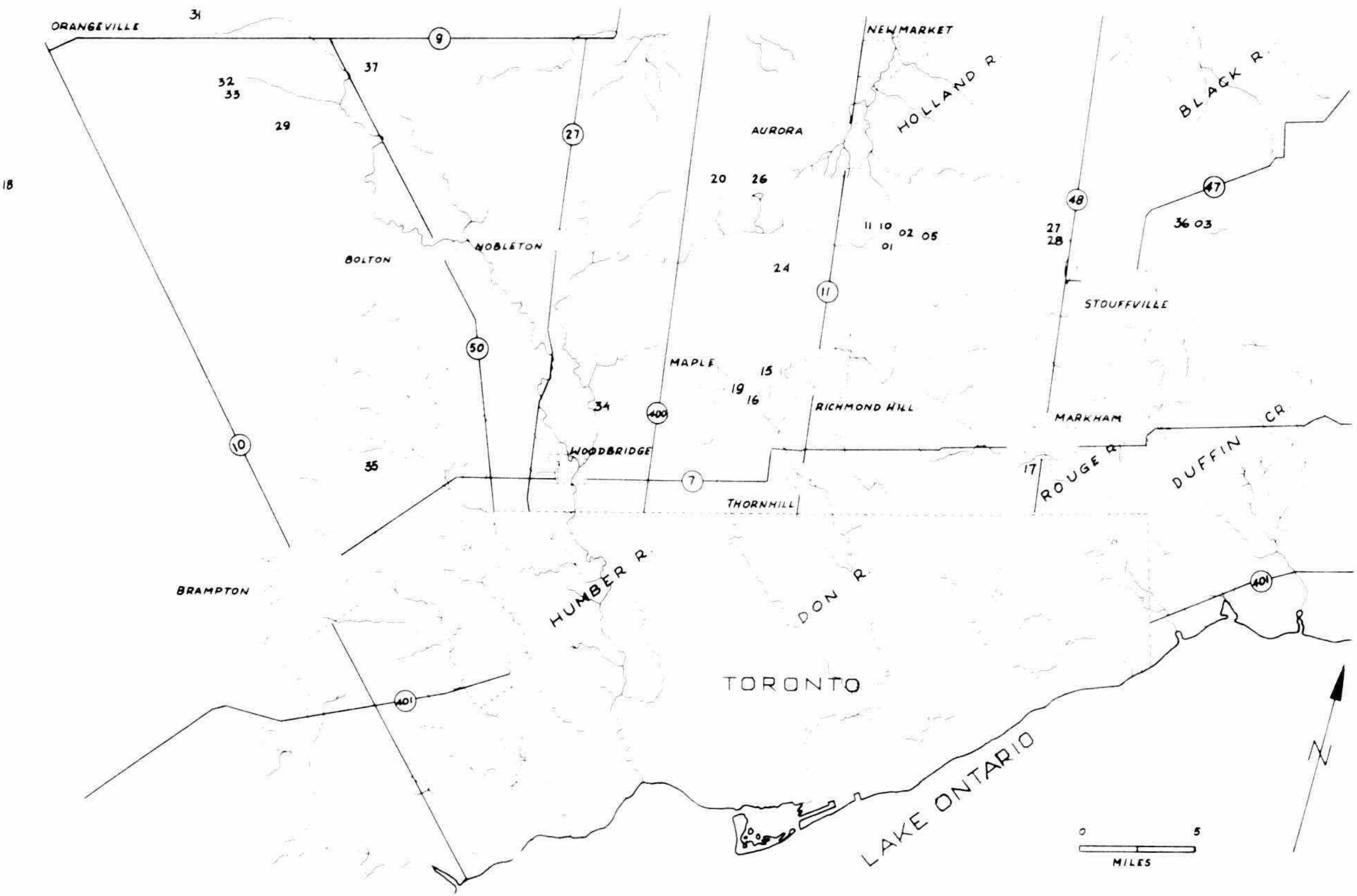

FIGURE 1. Location of the impoundments relative to the river systems in the study area.

Table 1: TYPES, DIMENSIONS AND WATER SUPPLY OF THE IMPOUNDMENTS

Impoundment Code	Type	Surface Area of Impoundment (Hectares)	Area of Watershed (Hestares)	Maximum Depth (Meters)	Origin of Water Supply	Nature of Outflow	Summer Discharge C.F.S.
37	Marsh	2.46	43	2.0	Runoff + springs	Intermittent	0.00
01	Kettle Lake				Table seepage	None apparent	0.00
02	" "	2.42	17	15.2	" "	Intermittent	0.00
05	" "	5.90	91	16.7	" "	"	0.00
10	" "	5.81	258	14.3	" "	"	0.00
11	" "	3.92	258	13.4	" "	"	0.00
20	" "	14.3	475	16.7	" "	"	-
26	" "	14.1	720	15.0	" "	"	-
27	Dam at Head Waters	0.65	127	2.6	Runoff + flowing springs	Continuous	0.15 - 0.62
28	" " " "	0.63	127	3.9	" " "	"	0.15 - 0.62
32	" " " "	1.26	541	4.0	" " "	"	-
33		1.13	541	4.8	" " "	"	-
19	" " " "	0.22	58	3.6	" " "	"	0.126 - 0.131
29	" " " "	0.43	49	2.0	" " "	"	0.00 - 0.017
18	Dam Downstream	6.8	2095	3.6	River + runoff	"	16.55
31	" "	2.69	666	1.8	From immediate environs	"	1.38 - 3.38
15	" "	2.67	454	4.3	" "	"	0.68 - 1.57
16	" "	1.01	360	2.4	" "	"	-
17		25.7	15780	4.6	" "	"	2.03 - 7.15

Cont'd....

Table 1 Cont'd....

Impoundment Code	Type	Surface Area of Impoundment (Hectares)	Area of Watershed (Hectares)	Maximum Depth (Meters)	Origin of Water Supply	Nature of Outflow	Summer Discharge C.F.S.
35	Flooded sand pit	2.74	None	9.1	Water table seepage	None	0.00 - 1*
34	" " "	2.37	346	6.1	Water table seepage + runoff	Intermittent	1.08 - 0.156
03	Dammed Gully near head waters.	12.9	100	7.6	Runoff + Intermittent stream	"	0.00
36	" " "	2.18	36	2.7	Runoff + Intermittent stream	"	0.00
06	By-pass	0.25	321	0.9	Runoff + river	"	0.00
07	"	0.11	321	0.9	?		0.00

* Estimated approximation

Groundwater is particularly important as a supply for headwater ponds, kettle lakes and flooded sand pits. The headwater ponds, with the possible exception of impoundment 29, are supplied by one or more permanent springs which account for the continuous outflow. Pond 19 is located on a large aquifer.

Soil types and water supply

The fraction of total precipitation which runs off in streams depends on the type of soils, physiographic features and extent of cultivation in the watershed. In view of the variety in the study area (Figure 2 and Table 2) one would expect the runoff to vary considerably from one watershed to another. Discharge data from the present study are not continuous enough to permit calculation of the ratio of total runoff to total precipitation. However, some estimates based on records of stream gauging and precipitation for 1967 (Table 3) ranged from 16 to 37% and averaged 26%. In general, watersheds throughout the study area can be described as agricultural (in contrast to forest or urban) and a runoff of about 30% is typical.

Besides affecting the amount of runoff, variation in soil types from one watershed to another (Table 2) is likely to affect its chemical composition. Impoundments located in light, infertile and uncultivated soils are likely to receive less material from the watershed than those located in heavier, more intensely cultivated soils. In general the headwater impoundments are located in eskers or moraines having lighter soils subject to little or no cultivation. Exceptions are kettle lakes 20, 26 and 10-11 which have (or have had in the recent past) dairy farms in the immediate watershed. In contrast,

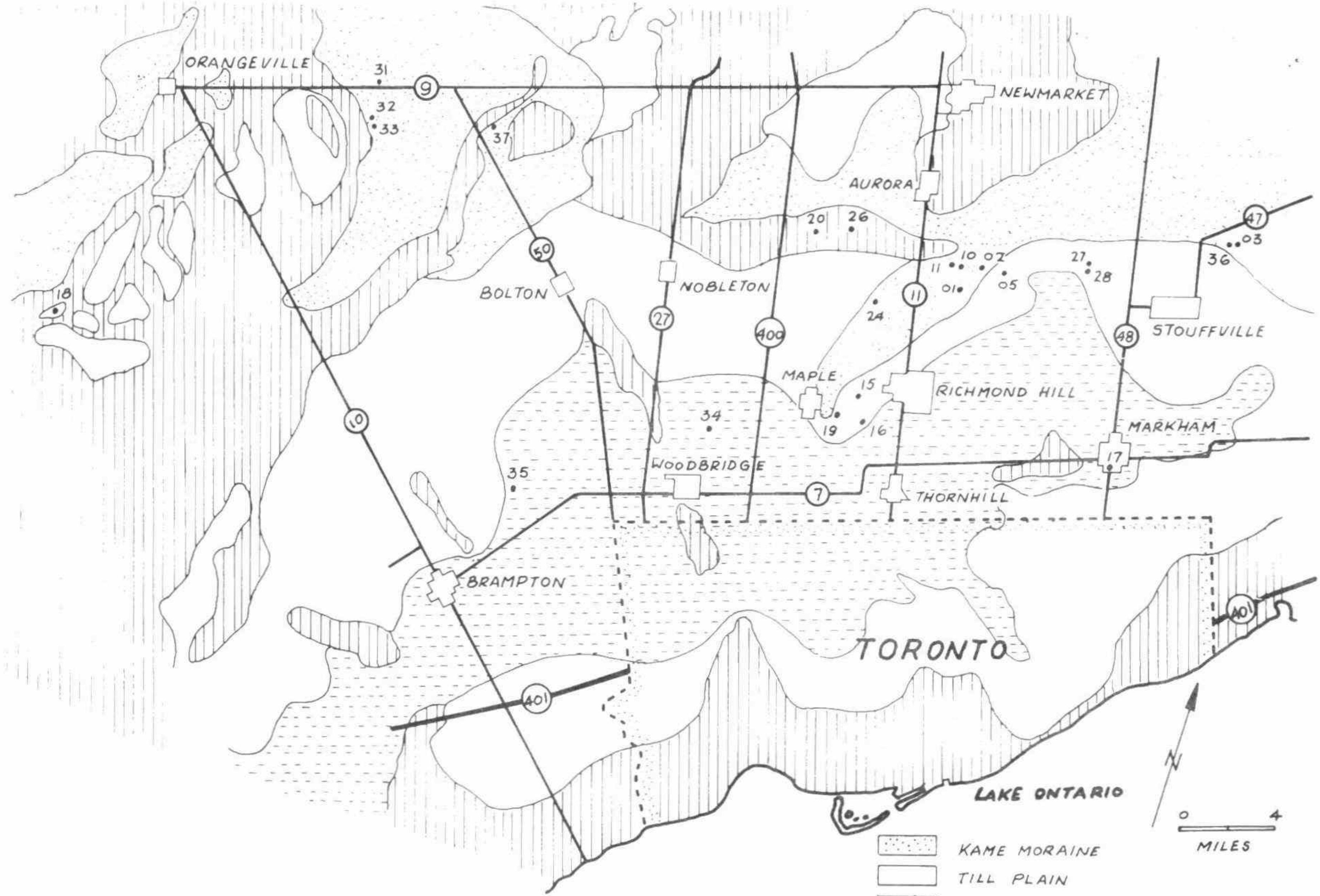

FIGURE 2. Location of the impoundments relative to the physiographic features in the study area (after Chapman and Putnam, 1951).

TABLE 2: SUMMARY OF SOIL TYPES ON THE WATERSHEDS OF THE RESPECTIVE IMPOUNDMENTS. (DATA EXTRACTED FROM SOIL SURVEYS PUBLISHED BY THE EXPERIMENTAL FARMS SERVICE, CANADA DEPARTMENT OF AGRICULTURE AND THE ONTARIO AGRICULTURAL COLLEGE).

Impoundment Code	Series	Type	Drainage	Surface Reaction	Great Soil Group	Topography	Main Fertility Needs*
31	Tioga	loamy sand	good	medium acid	podzol	smooth, gently to irregular, steeply sloping	
	Bondhead	loam	good	neutral	grey-brown podzolic	smooth, moderately to steeply sloping	
15	Oneida	clay loam	good	slightly to medium acid	grey-brown podzolic	smooth, moderately sloping	organic matter, (phosphate)
16	Peel	clay	imperfect	neutral to slightly alkaline	grey-brown podzolic	smooth, gently sloping	(organic matter, phosphate)
17	Milliken	sandy loam	imperfect	slightly acid	grey-brown podzolic	smooth moderately to gently sloping	phosphate, (organic matter, potash)
	Brighton	sandy loam	good	neutral to slightly alkaline	grey-brown podzolic	smooth very gently sloping	organic matter, phosphate, potash
	Peel	clay	imperfect	neutral to slightly alkaline	grey-brown podzolic	smooth, gently sloping	(organic matter, phosphate)
35	Caledon	loam (gravelly)	good	slightly acid to neutral	grey-brown podzolic	smooth gently sloping to smooth moderately sloping	phosphate, potash, (organic matter)
34	Fox	sandy loam (gravelly)	good	slightly acid to netral	grey-brown podzolic	smooth very gently sloping	organic matter, phosphate, potash
	King	clay loam (gravelly)	good	neutral	grey-brown podzolic	smooth moderately to irregular steeply sloping	(organic matter, phosphate)

TABLE 2: Cont'd.....

Impoundment Code	Series	Type	Drainage	Surface Reaction	Great Soil Group	Topography	Main Fertility Needs*
03 36	Woburn	loam and sandy loam	good	neutral	grey-brown podzolic	rolling	organic matter, phosphate (potash)
	Muck	variable	very poor	neutral	bog	depressional	phosphate, potash
06 07	Schomberg	clay loam	good	slightly alkaline	grey-brown podzolic	smooth moderately sloping to irregular steeply sloping	
37	Brighton	sandy loam	good	neutral to slightly alkaline	grey-brown podzolic	smooth gently sloping	organic matter, phosphate, potash
	Pontypool	sandy loam	good	slightly alkaline to neutral	grey-brown podzolic	irregular steeply sloping	organic matter, phosphate, potash
	Muck	variable	very poor	neutral to alkaline	bog	depressional	phosphate, potash
	Bottom Land	variable	variable	variable	alluvial	variable	variable
01	Peel	clay	imperfect	neutral to slightly	grey-brown podzolic	smooth gently sloping	(organic matter, phosphate)
	Woburn	loam	good	slightly acid	grey-brown podzolic	smooth steeply sloping	organic matter, phosphate, (potash)
02	Peel	clay	imperfect	neutral to slightly alkaline	grey-brown podzolic	smooth gently sloping	(organic matter, phosphate)
05	Woburn	sandy loam	good	slightly acid	grey-brown podzolic	smooth steeply sloping	organic matter, phosphate, (potash)

TABLE 2: Cont'd....

Impoundment Code	Series	Type	Drainage	Surface Reaction	Great Soil Group	Topography	Main Fertility Needs*
10 11	Brighton	sandy loam over gravel	good	neutral to slightly alkaline	grey-brown podzolic	smooth very gently sloping	organic matter, phosphate,potash
20	King	clay loam steep phase	good	neutral	grey-brown podzolic	smooth moderately to irregular steeply sloping	(organic matter, phosphate)
26	Bottom land	variable	variable	variable	alluvial	variable	variable
	King	clay loam steep phase	good	neutral	grey-brown podzolic	smooth moderately to irregular steeply sloping	(organic matter, phosphate)
27 28	Milliken	loam	imperfect	slightly acid	grey-brown podzolic	smooth moderately to gently sloping	phosphate,(organic matter, potash)
32 33	Pontypool	sandy loam	good	slightly alkaline to neutral	grey-brown podzolic	irregular steeply sloping	organic matter, phosphate,potash
19	Oneida	clay loam	good	slightly to medium acid	grey-brown podzolic	smooth moderately sloping	organic matter, (phosphate)
29	Pontypool	sandy loam	good	slightly alkaline to neutral	grey-brown podzolic	irregular steeply sloping	organic matter phosphate,potash
18	Caledon	fine sandy loam	good	slightly acid to neutral	grey-brown podzolic	smooth gently sloping to smooth moderately sloping	phosphate, potash (organic matter)
	Muck	variable	very poor	neutral to alkaline	bog	depressional	phosphate, potash

* Bracketed fertility needs are minor needs, unbracketed needs are major needs.

TABLE 3: RUNOFF AT VARIOUS LOCATIONS IN THE STUDY AREA ESTIMATED FROM 1967 STREAM GAUGING AND WEATHER RECORDS

Stream	Discharge Gauging Station	Rain Gauging Station*	Watershed in acres	Annual Precipitation Feet	Annual Precipitation Acre-feet	Annual Runoff Acre-feet	Runoff Precipitation
Duffin	Pickering	Pickering	70,400	2.98	210,000	67,460	0.311
"	Greenwood	"	32,000	2.98	95,300	24,490	0.370
Rouge	Markham	Markahm	46,100	3.16	145,000	36,230	0.314
Little Don	Don Mills	Willowdale	32,000	2.77	88,000	29,230	0.304
Humber	Claireville	Woodbridge	48,000	2.94	141,000	31,010	0.220
"	Pine Grove	"	48,700	2.94	143,000	22,580	0.157
Cold Creek	Bolton	"	15,350	2.94	45,200	10,530	0.233
Humber	Humber Trails	"	23,200	2.94	65,200	11,230	0.172
"	Weston	Weston	198,000	2.79	553,000	136,700	0.247
"	Elder Mills	Erindale	74,700	3.06	229,000	55,450	0.242
"	Cedar Mills	Albion	41,700	2.87	120,000	33,230	0.276
Mean Runoff/Precipitation Ratio							0.258

* i.e. Rain Gauging Station Nearest the Discharge Gauging Site.

1 Acre Foot = 0.123 Hectare Metres

the downstream ponds 15, 16 and 17 are located in till plains subject to intensive agriculture. The soils in all of the watersheds appear to be naturally low in organic matter and phosphorus. Potassium is also in short supply in some instances. In cultivated areas these deficiencies are often offset by applications of fertilizer.

Meteorological conditions

Solar radiation, precipitation and air temperatures in the study area in 1970 are summarized in Table 4. Characteristically, insolation and air temperatures followed sinusoidal seasonal trends with temperature lagging about a month behind insolation. The mean radiation rose from a minimum of 92 Langleys per day in December to a maximum of 536 in June, while the mean air temperature ranged from $-11.0^{\circ}C$ in January to $20.2^{\circ}C$ in July. Mean air temperatures were remarkably uniform throughout the study area. In contrast, the distribution of precipitation was more irregular with respect to both month and locality. The annual precipitation for the study area averaged 76 cm. During the summer of 1970 the precipitation was somewhat higher in the north-western (Orangeville) and central (Oak Ridges) regions than in other parts of the study area.

McCombie (1959) found that there was a close correlation between the monthly mean surface water temperature of South Bay, Manitoulin Island, and the monthly mean air temperature during the ice-free months. A similar situation was observed in the present study (Figure 3). It should be noted that the seasonal trend of surface water temperature actually followed the trend of air temperature more closely than the radiation.

TABLE 4: RADIATION, PRECIPITATION AND AIR TEMPERATURES AT DIFFERENT POINTS IN THE STUDY AREA IN 1970, BASED ON THE METEOROLOGICAL SERVICES MONTHLY WEATHER SUMMARIES.

	MEAN DAILY RADIATION IN LANGLEYS											
	Jan	Feb	Mar	April	May	June	July	Aug.	Sept.	Oct	Nov	Dec
Toronto	119	203	303	424	413	526	475	456	299	175	103	89
Toronto M.R.S.	153	243	356	448	422	549	483	471	317	158	103	100
Scarborough	133	215	327	443	419	535	487	464	291	172	102	89
Overall Means	135	220	328	438	418	536	481	458	302	168	103	92

	TOTAL PRECIPITATION IN CM												
	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Total for Yea
Toronto I.A.P.	2.56	2.97	4.37	8.13	5.66	3.81	11.35	11.33	6.17	6.37	4.49	8.18	75.39
Brampton	2.11	3.12	5.05	7.57	5.46	4.55	7.77	11.02	6.88	6.98	4.65	9.85	75.01
Orangeville	4.52	2.31	4.87	7.26	7.08	5.36	9.07	8.64	11.07	10.11	5.71	8.03	84.03
Oak Ridges	6.88	3.40	4.83	9.42	6.43	3.94	12.57	4.60	7.92	7.01	6.20	8.33	81.53
Markham	5.13	2.79	5.51	10.00	5.51	2.67	8.74	4.83	6.32	7.80	5.79	8.66	73.75
Stouffville	5.71	2.92	4.93	7.06	6.20	4.14	14.27	3.48	6.68	7.24	5.66	7.72	76.01
Overall Means	4.48	2.92	4.93	7.90	6.06	4.08	10.63	7.31	7.50	7.58	5.42	8.46	77.62

	MEAN AIR TEMPERATURE IN °C											
	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Toronto I.A.P.	-10.8	-6.5	-2.2	7.3	12.0	17.1	20.6	19.6	15.3	10.1	3.9	-5.6
Brampton	-10.0	-6.5	-1.94	6.7	12.5	17.9	20.9	20.2	16.0	10.4	4.2	-5.3
Orangeville	-11.8	-8.6	-4.9	6.8	11.8	16.1	19.0	18.0	14.4	9.2	2.8	-6.7
Oak Ridges	-11.5	-8.1	-2.8	6.2	11.8	17.6	20.3	19.8	15.4	10.0	3.1	-6.3
Markham	-11.7	-7.4	-2.3	6.4	11.9	17.0	20.2	19.0	15.0	10.0	4.2	-5.9
Overall Means	-11.0	-7.4	-2.7	6.7	12.1	17.1	20.2	19.3	15.2	9.9	3.7	-5.9

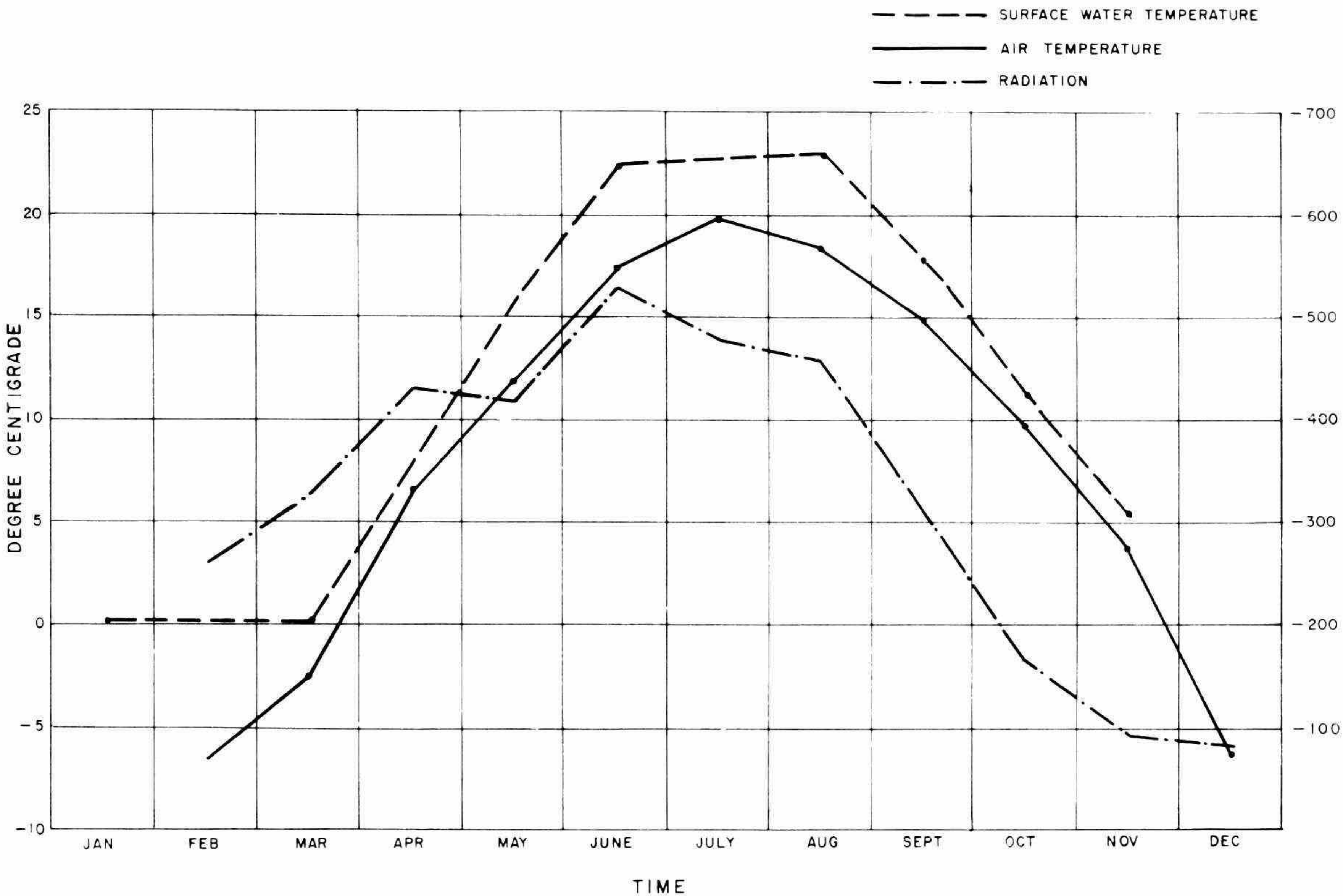

FIGURE 3. Seasonal trends of mean radiation, air temperatures and surface water temperatures in the study area during 1970.

During the summer water levels in the kettle lakes and other impoundments which have no outflow drop about 30 cm as a result of evapo-transpiration. According to the computations and maps published by Ferguson, O'Neil and Cork (1970) the mean annual evaporation from lake surfaces in our study area is 71 to 81 cm. The monthly mean for June is 12 to 15 cm.

METHODS

During the initial phase of this study the lakes and ponds were mapped and sounded and where possible, occasional measurements were made of the rate of discharge. Permanent sampling stations were established at inlets, outlets and deepest points in each impoundment. In the larger lakes, or those having more than one basin, additional deep water stations were established. The impoundments were sampled at regular intervals between May and October and occasionally during the winter months.

Water temperatures and transparency

Water temperatures were measured with a resistance thermometer, equipped with a thermistor probe, at approximately two-week intervals. At shallow water stations, temperatures were measured at the surface and bottom or mid-depth only. At deep water stations temperatures were read at intervals of 0.33 to 1m from surface to bottom, to obtain vertical profiles. Transparency of the water was measured with a Secchi disc at the deep water station(s) on each impoundment. Readings were taken in mid-morning or mid-afternoon when the sun was at a high angle and penetration was maximal.

Routine Chemical analyses

At approximately 2 week intervals, water samples were collected for the following routine analyses: pH, specific conductance, total alkalinity, calcium hardness, dissolved oxygen and carbon dioxide.

At the shallow stations, water samples were taken from surface or mid-depth only. Both surface and bottom samples were collected at all deep water stations and additional samples were taken at two or three meter intervals in the thermally stratified lakes. Surface samples were dipped directly into glass or plastic bottles and the remaining samples were collected with a Kemmerer sampler.

Specific conductance and pH were measured in the laboratory utilizing conductivity and pH meters. Specific conductance readings were taken at room temperatures and corrected to 25°C according to the standard curve for 0.1 N KCl solution (Standard Methods of Water Analyses, 12th Edition, page 281).

The remaining analyses were performed in the field using kits made by the Hach Chemical Company, Ames, Iowa.

Detailed chemical analyses

On four or five separate occasions throughout the season additional water samples were collected and forwarded to the Laboratory Branch, Ministry of the Environment, for the following analyses: total dissolved solids, total and soluble phosphorus, Kjeldahl, ammonia, nitrite and nitrate nitrogen, silica as SiO_2, calcium, magnesium, iron, manganese, chloride and sulphate. All analyses were performed according to procedures outlined in Standard Methods (A.P.H.A. et al. 1965).

The samples were taken from the surface and bottom at deep stations and from mid-depth at shallow stations. Again, surface samples were dipped directly into bottles and the bottom and mid-depth samples were collected with a Kemmerer sampler.

Sediments

Sediment samples were collected from both the established sampling stations and from shallow weedy areas by means of a 6" x 6" Eckman dredge. The top centimeter was removed from each dredge sample, placed in a 4 oz jar and forwarded to the Laboratory Branch for chemical analyses. The concentrations of nitrogen, phosphorus, iron and manganese as well as the percent loss on ignition were determined for each sample. Also, the quantities of nitrate, ammonia, total Kjeldahl nitrogen, total and soluble phosphorus, iron, manganese and calcium which could be extracted with water under both aerobic and anaerobic conditions were determined for samples collected during 1969. The analytical methods are described by Brydges (1970).

Aquatic Macrophytes

Distribution and abundance of the aquatic plants was assessed visually in all impoundments. In seven selected impoundments, the standing stock of the macrophytes was determined by collecting all plant material growing within randomly placed ¼ m^2 quadrats. The plants were collected in late July and August, using self-contained underwater breathing apparatus (S.C.U.B.A.).

Following removal, the plants were washed, sorted by species and placed on screens to remove adherent water prior to determining the fresh weights. The plant material was air dried in a well ventilated room and was weighed on several successive days until a constant dry weight was reached. Dry plant material from the seven selected impoundments and several additional ones was submitted to the Laboratory for chemical analyses including calcium, magnesium, manganese, iron, nitrogen, phosphorus and the percent loss on ignition.

The analytical methods used are detailed in Appendix I.

Chlorophyll and Phytoplankton

Composite water samples for chlorophyll analyses and phytoplankton enumerations were taken from the deep water stations at about two week intervals. The samples were collected with a composite sampler (Michalski 1971) which was lowered through the euphotic zone (Secchi disc reading x 2) and forwarded to the laboratory. Chlorophyll determinations were completed following the method of Brydges (1971). The algal samples were concentrated by allowing the cells to settle for 72 to 96 hours and then syphoning off the supernatant. The concentrate was pipetted into a Sedgwick-Rafter counting cell and the results were recorded in areal standard units (a.s.u.) One areal standard unit equals 400 square microns.

RESULTS

The aquatic environment: physical aspects

Water temperatures

The seasonal trends in temperature of surface and bottom waters of the impoundments are shown in Figures 4 and 5. Figure 4 represents typical conditions in impoundments up to 4 or 5m maximum depth while Figure 5 illustrates conditions in the kettle lakes, which are 13 to 17m deep. Conditions in pond 03, which has a maximum depth of about 8m, are intermediate.

Spring turnover occurred in late March or early April, after the ice disappeared. None of the impoundments were meromictic.

Figures 6 and 7 show typical vertical profiles of temperature and dissolved oxygen at the height of summer stratification in shallow and deep impoundments, respectively. In ponds less than 3 to 5m deep and in the upper 5 to 8m of the deeper impoundments the changes in temperature were comparatively small and gradual, suggesting that wind mixing was quite effective to these depths. On the other hand there was a sharp thermocline between 3 and 8m in the kettle lakes and temperatures below 8m did not exceed 10 or 15°C at any time.

Surface temperatures peaked about mid-August. Autumnal turnover occurred in impoundments less than 4 or 5m deep in mid-September and during October or early November in the kettle lakes.

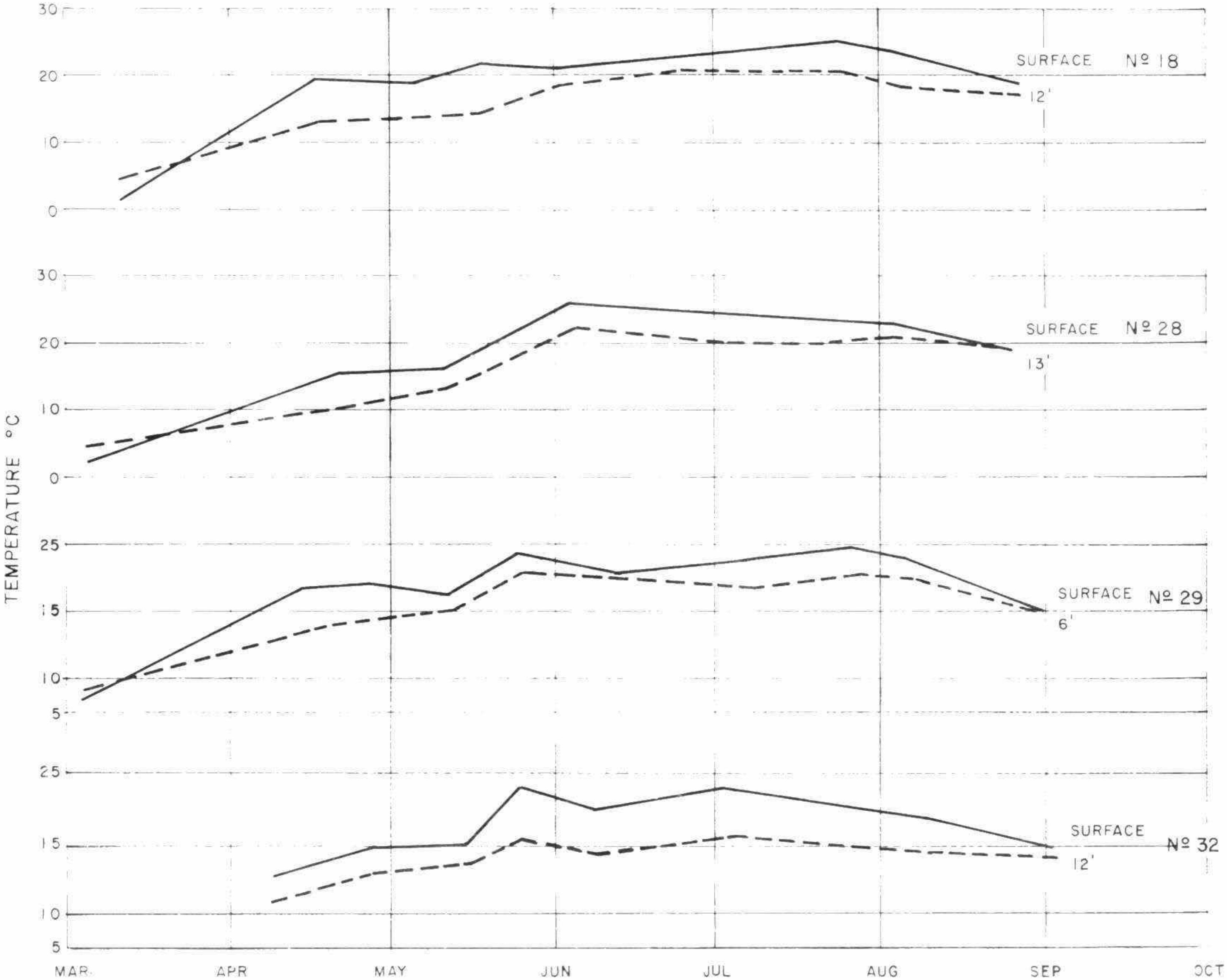

FIGURE 4. Seasonal trends in water temperatures in shallow impoundments during 1970.

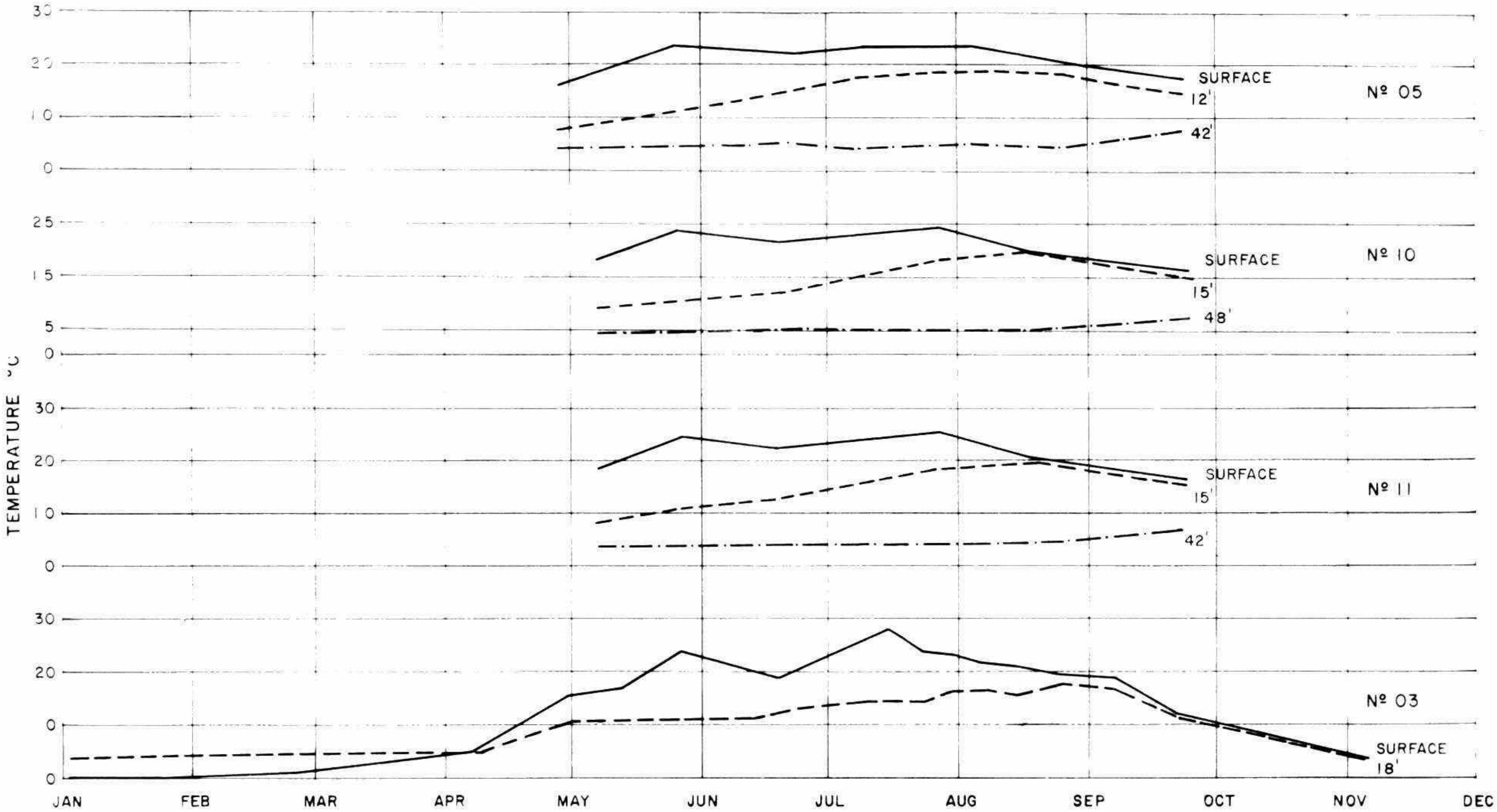

FIGURE 5. Seasonal trends in water temperatures in deep impoundments during 1970.

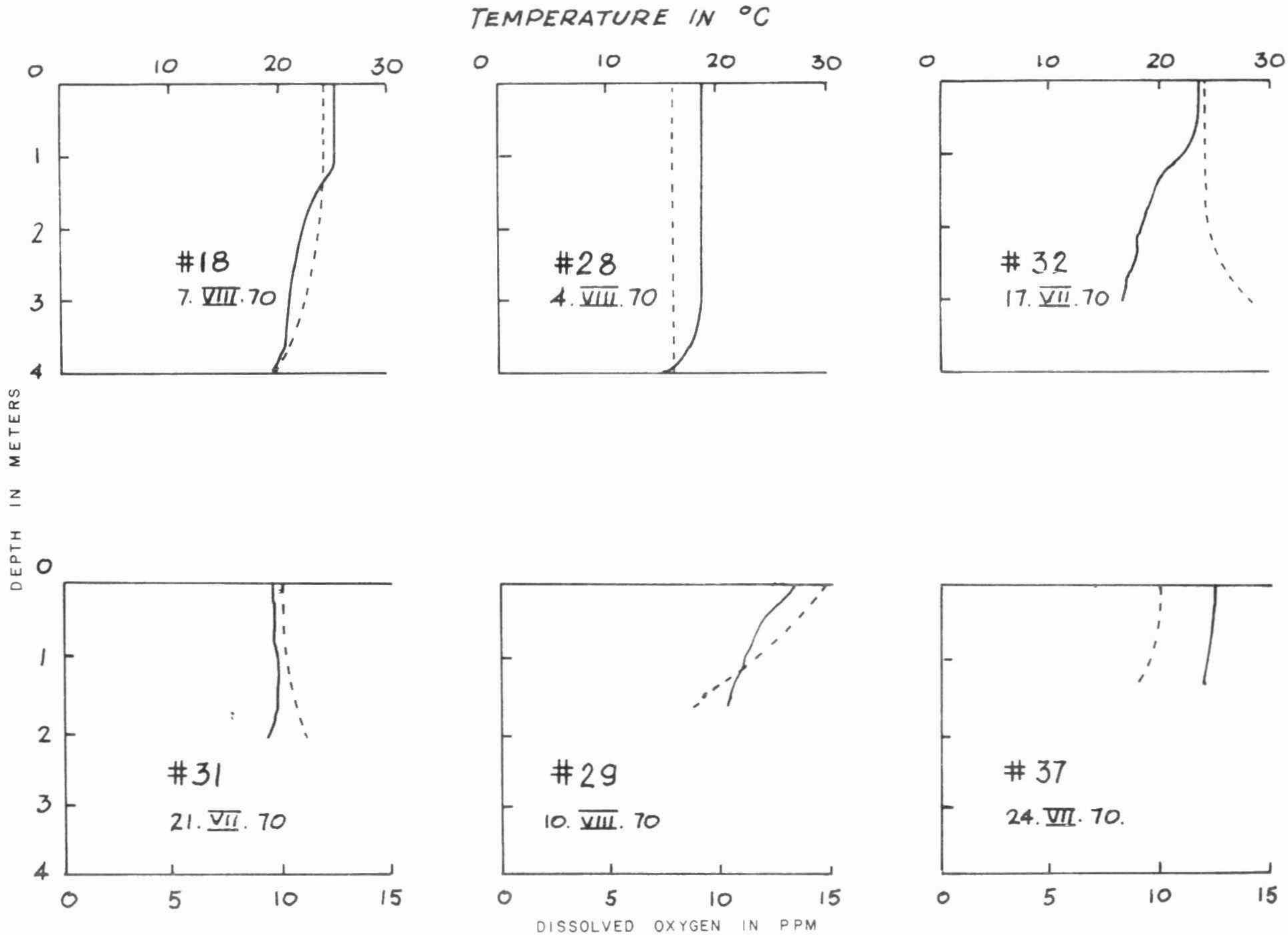

FIGURE 6. Typical mid-summer profiles of temperature and dissolved oxygen in shallow impoundments. The solid line represents the temperature and the dotted line denotes the dissolved oxygen.

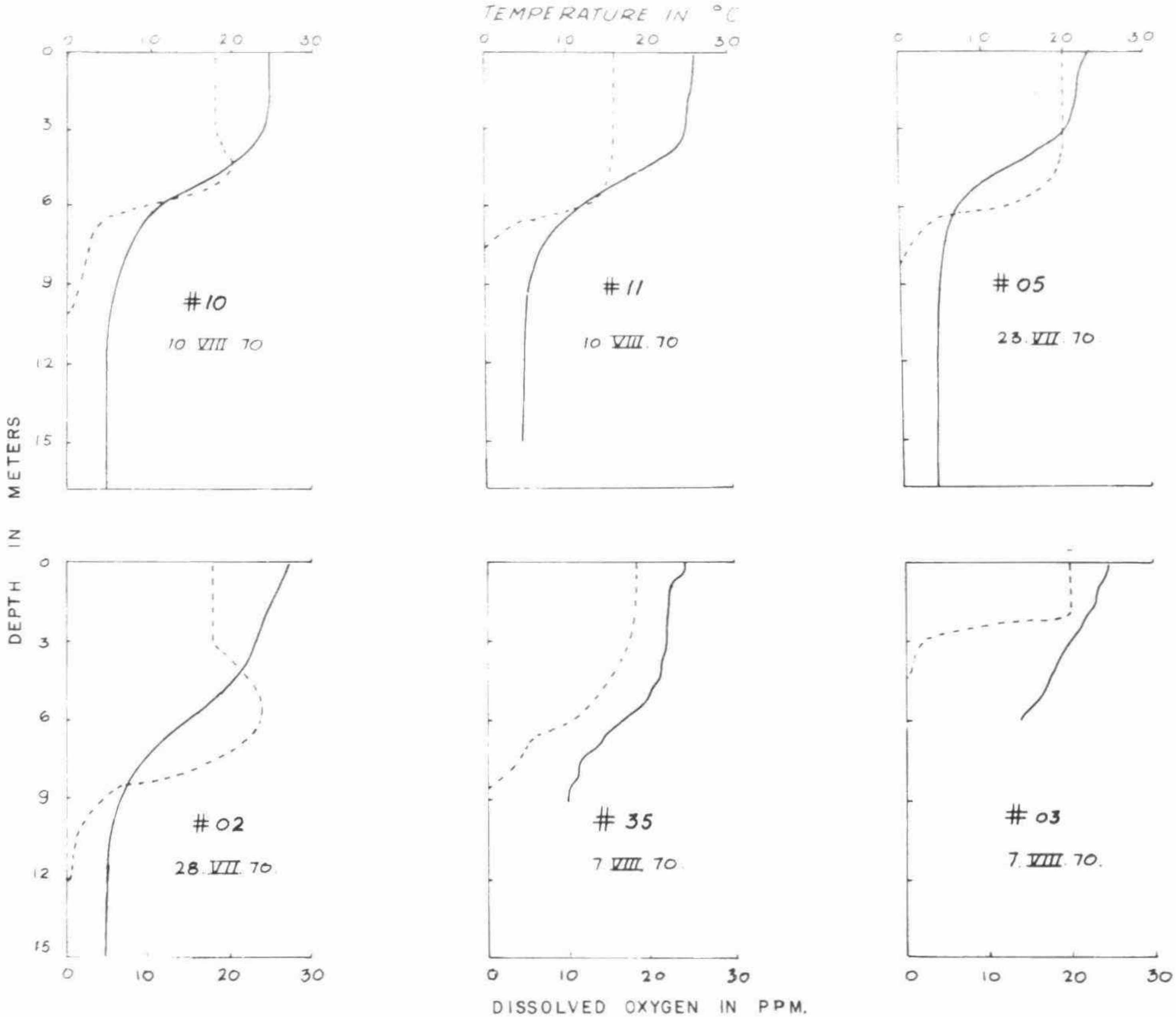

FIGURE 7. Typical mid-summer profiles of temperature and dissolved oxygen in deep impoundments. The solid line represents the temperature and the dotted line denotes the dissolved oxygen.

In wintertime the impoundments were inversely stratified with respect to temperature; the water was 0.5 to 2.0°C immediately below the ice and 3 or 4 °C near the bottom (Figures 8 and 9).

Impoundments which had considerable and continuous water supplies and consequently higher flushing rates, tended to stratify less strongly than those with small or intermittent supplies. Bays or other portions of the impoundments which were off the main stream (e.g. station 4 Pond #15) stratified more strongly than portions in direct line between the inlet and outlet. In pond #17 where the original stream bed formed a narrow trench along the basin, there was a sharp thermal stratification along this depression.

Water transparency

Although individual Secchi disc readings varied greatly from one sampling date to another, the means indicate that the water was more transparent in some of the impoundments than in others (Table 5). In 1969 mean readings ranged from 0.9 to 5.8m while in 1970 they ranged from 0.7 to 5.2m. In both years, kettle lake #02 was much clearer than any of the other impoundments and the Secchi disc readings coincided with the top of the thermocline.

Lighting conditions, silt load and phytoplankton concentrations were the most important factors affecting water transparency in these impoundments. With the possible exception of kettle lake #01, water colour was negligible. In the on-stream impoundments silt loads were significant during spring runoff and following heavy rains. In ponds #03, 34 and 35, where unconsolidated clay soils were exposed to wave action, the silt load increased noticeably during windy weather.

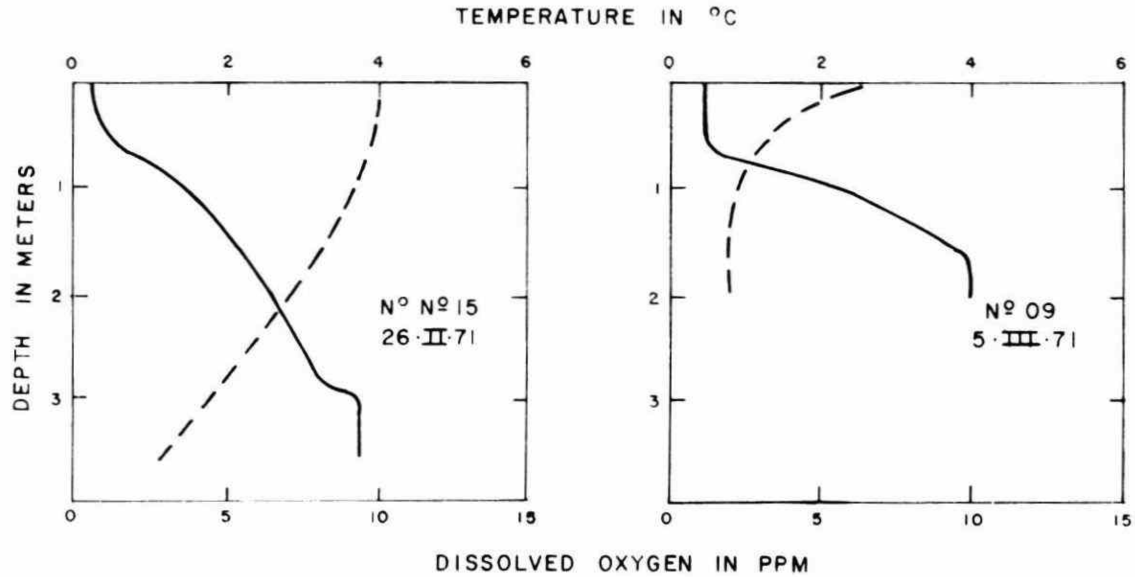

FIGURE 8. Typical mid-winter profiles of temperature and dissolved oxygen in shallow impoundments. The solid line represents the temperature and the dotted line denotes the dissolved oxygen.

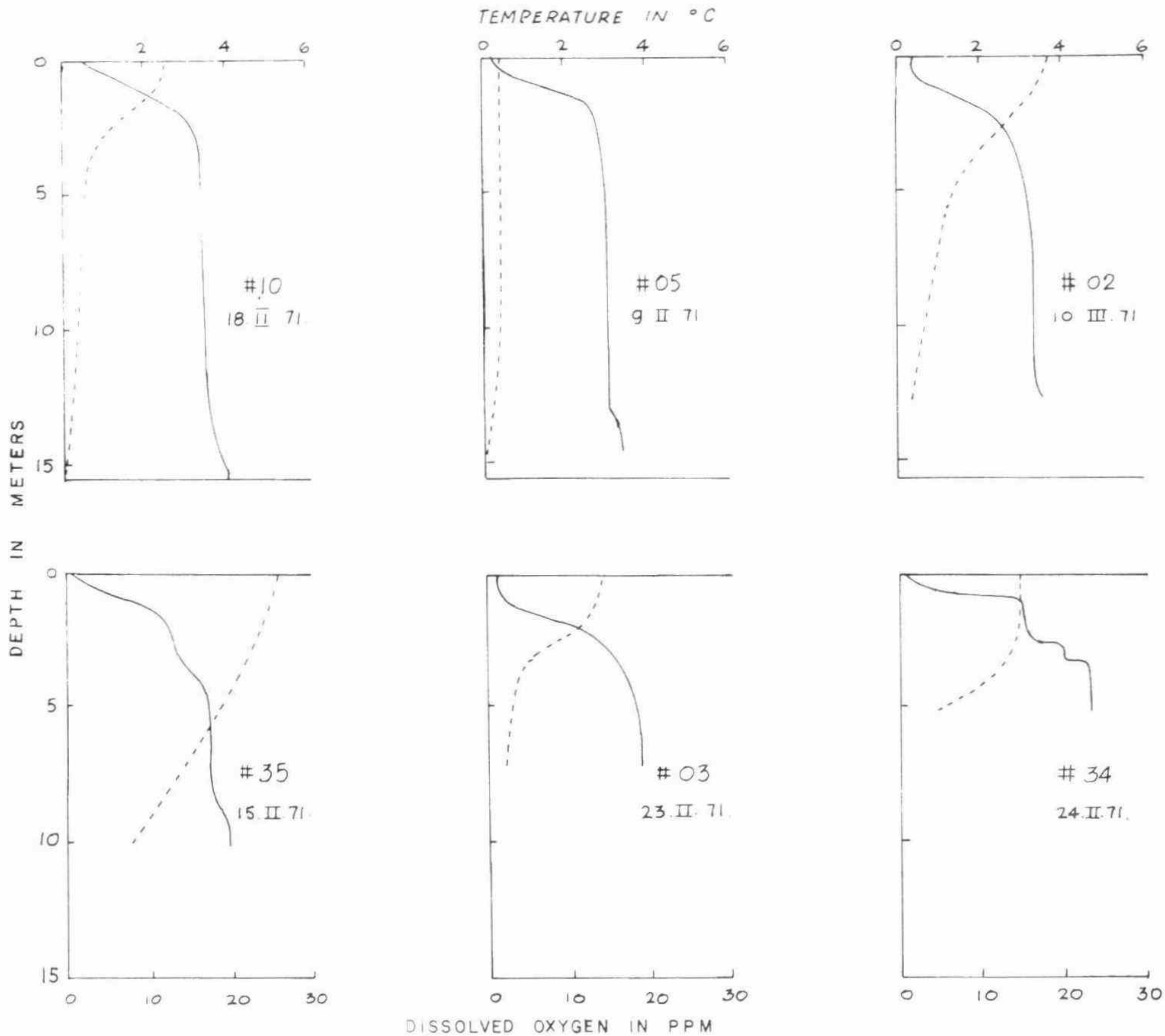

FIGURE 9. Typical mid-winter profiles of temperature and dissolved oxygen in deep impoundments. The solid line represents the temperature and the dotted line denotes the dissolved oxygen.

The aquatic environment: chemical aspects

Dissolved oxygen and carbon dioxide

Examples of seasonal trends of dissolved oxygen in deep and shallow impoundments are given in Figures 10 and 11. In general, atmospheric exchange and wind stirring kept the surface layers saturated with oxygen while photosynthesis caused supersaturation at times. In contrast, dissolved oxygen concentrations in the deeper layers tended to decline during the summer as a result of decomposition of organic detritus and respiration. The changes in dissolved oxygen concentrations from surface to bottom were usually small in impoundments less than 5m deep. On the other hand there was a sharp themocline between 3 and 8m in the kettle lakes and layers below 8m were anoxic and contained high concentrations of hydrogen sulphide.

Since the kettle lakes and the two quarry ponds intersect the water table, their hypolimnions may contain some ground water of deep origin. Such water usually lacks oxygen and contains high concentrations of carbon dioxide and hydrogen sulphide. Anoxic conditions also developed in the bottom layers of pond #06 which is only slightly more than a meter deep. This pond lies in a sheltered valley and has no flushing.

Low oxygen concentrations were found in the deeper layers of Pond #03 during the summer stratification and in mid-winter. During the summer of 1968 there was a bloom of blue-green algae in this impoundment and anoxic conditions occurred in the deeper layers during the late summer, fall and winter. The bloom recurred in 1969 but disappeared in late summer following applications of algicide. Dissolved oxygen concentrations improved in 1970.

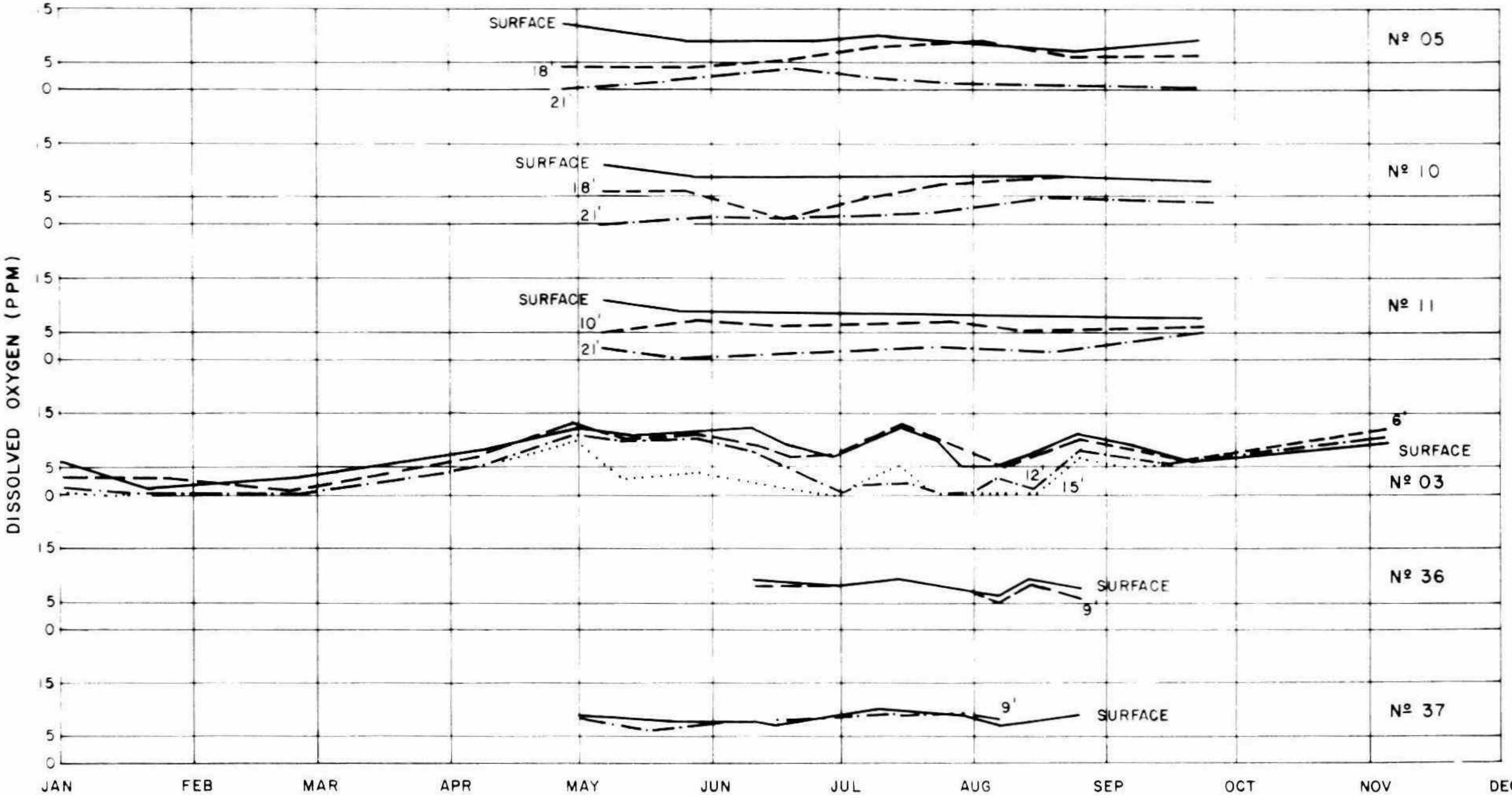

FIGURE 10. Seasonal trends in dissolved oxygen concentrations in deep impoundments during 1970.

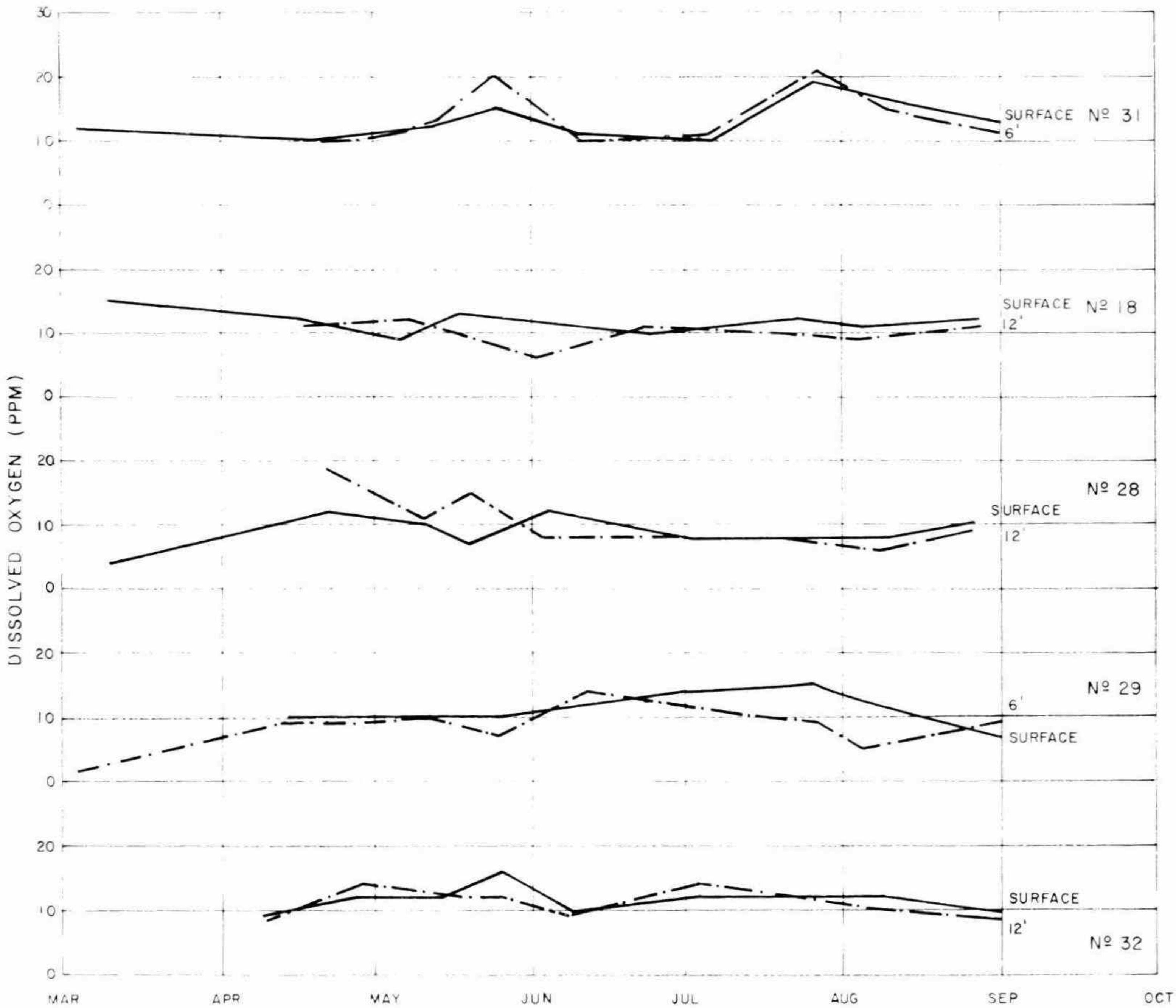

FIGURE 11. Seasonal trends in dissolved oxygen concentrations in shallow impoundments during 1970.

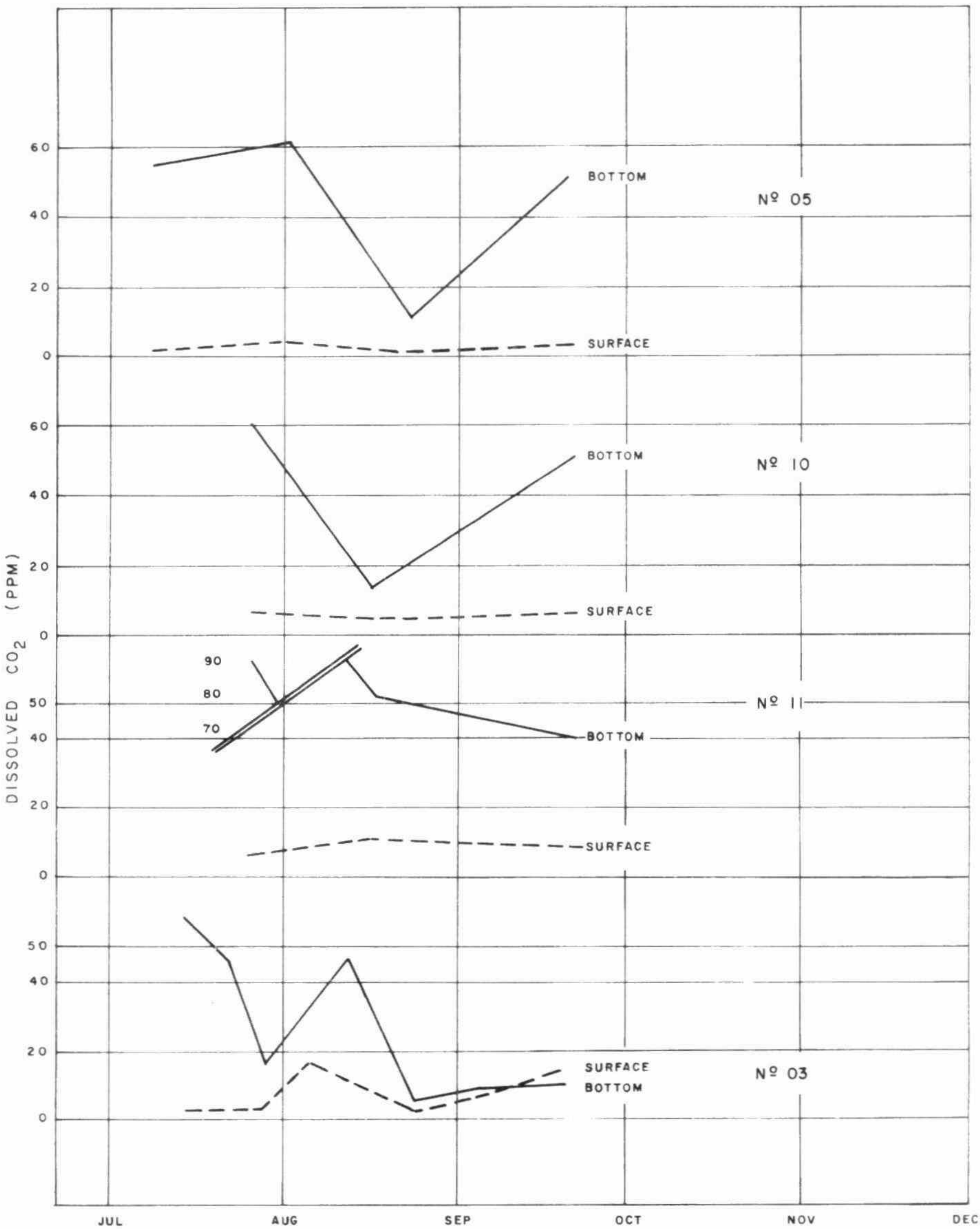

FIGURE 12 Seasonal trends in carbon dioxide concentrations in deep impoundments during 1970.

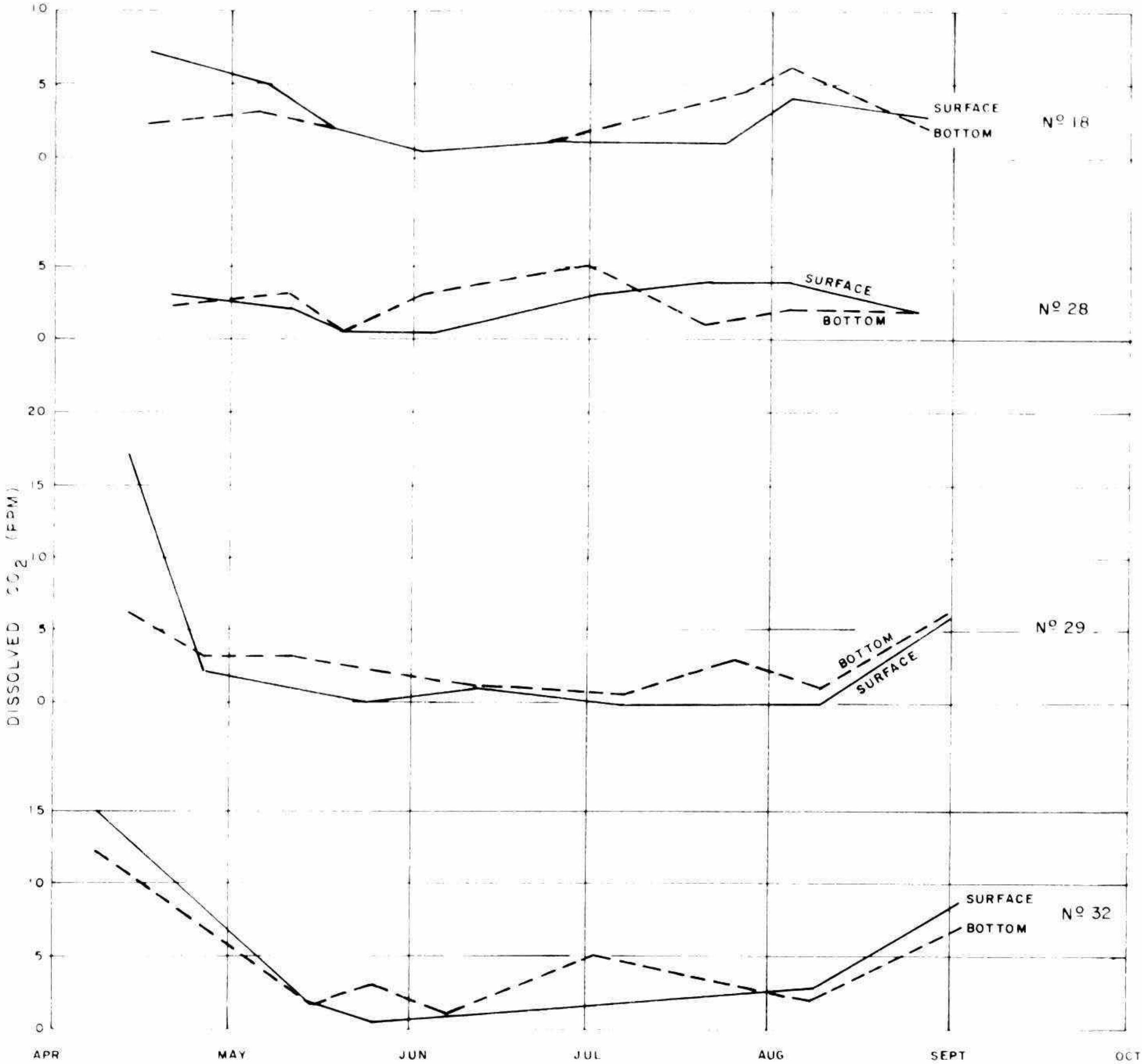

FIGURE 13. Seasonal trends in carbon dioxide concentrations in shallow impoundments during 1970.

The seasonal trends of carbon dioxide concentrations in surface and bottom layers of deep and shallow impoundments are shown in Figures 12 and 13. Carbon dioxide concentrations in surface waters were of the order of 0 to 10 ppm but varied considerably from one sampling date to another. Photosynthesis of both phytoplankton and rooted aquatic plants would tend to reduce the carbon dioxide concentrations in the epilimnion.

In ponds up to 5 to 6 m deep the difference between the carbon dioxide concentrations in the surface and bottom waters was of the order of 5-10 ppm, provided anoxic conditions did not develop. Where anoxic conditons did occurr the differences were greater, especially in the deep, strongly-stratified kettle lakes and flooded sand pits. Carbon dioxide concentrations in the hypolimnion of these bodies ranged from 20 to 60 ppm. The higher concentrations of carbon dioxide in the deeper layers were undoubtedly the result of respiration, decompositon and the reduction or absence of photosynthesis.

Hardness

As might be expected from the variety of soil types and physiographic features in the study area, the hardness varied widely from one impoundment to another. Average total hardness for the surface layers ranged from 53 to 307 ppm while those for bottom layers ranged from 55 to 311 ppm (Table 5 and 6).

During summer hardness decreased in the surface layers and increased in the deeper layers (Figure 14). The difference between surface and bottom conditions was greatest in the kettle lakes during summer stratification.

TABLE 5: MEAN CHEMICAL DATA FOR SURFACE WATER SAMPLES FROM ANALYSES MADE IN THE FIELD IN 1970

Impoundment Code	Number of Samples	Total Hardness	Calcium Hardness	Total Alkalinity	Spec Cond.	pH.	Secchi Disc (m)
37	8	53	40	60	82	6.9	-
01	2	58	45	65	130	7.2	0.94
02	2	114	88	101	241	8.4	6.37
36	8	135	93	126	241	8.2	2.25
05	7	141	106	123	250	8.2	1.71
20	1	142	97	125	252	8.1	1.19
06	3	150	127	141	330	8.1	-
03	19	161	120	157	282	8.1	0.85
07	2	164	104	147	356	8.1	-
28	8	180	118	148	255	7.6	1.46
27	8	181	126	158	268	7.5	-
10	6	182	150	172	328	8.4	3.69
29	9	185	127	152	239	8.2	1.37
11	6	188	151	164	324	8.3	3.53
18	8	203	128	169	305	7.9	1.70
33	7	208	142	166	300	7.7	2.65
26	1	213	162	202	391	8.3	1.37
31	8	216	146	164	328	7.8	0.97
32	7	221	152	176	318	7.7	-
17	4	232	173	204	515	7.8	0.64
34	3	232	167	155	487	8.0	2.40
16	2	256	219	223	519	7.8	0.73
15	3	260	205	214	400	4.7	1.71
19	5	277	202	172	549	8.2	1.95
35	5	301	227	143	592	8.2	2.13
34	1	307	228	178	516	8.0	-

All concentrations are in ppm; specific conductance is in micromhos/Cm^2 at 25°C

TABLE 6: MEAN CHEMICAL DATA FOR BOTTOM WATER SAMPLES FROM ANALYSES MADE IN THE FIELD IN 1970

Impoundment Code	Station	Number of Samples	Total Hardness	Calcium Hardness	Total Alkalinity	Spec. Cond.	pH
37	2	8	55	40	60	82	6.9
01	1	2	64	53	69	130	7.0
36	1	7	124	91	124	236	8.0
06	1	2	130	95	135	287	8.0
07	4	3	142	112	138	337	8.3
02	1	1	177	136	193	259	7.4
28	3	8	180	116	143	254	7.6
03	1	19	181	143	188	310	7.6
29	3	9	188	137	160	328	7.6
20	1	1	189	144	181	361	7.7
18	4	8	203	133	169	309	7.9
05	1	7	205	163	274	413	7.2
33	3	7	218	147	176	314	7.6
31	2	8	220	156	169	341	7.9
32	2	7	237	192	183	340	7.6
26	1	1	240	192	241	458	7.4
17	1	4	247	183	251	565	7.5
10	1	6	250	226	261	500	7.5
34	2	3	254	216	189	547	7.7
11	3	6	272	230	257	540	7.2
15	4	3	274	177	214	427	7.8
16	1	2	282	239	249	547	7.8
19	1	5	293	260	214	596	7.6
35	1	4	311	228	182	638	7.7

All concentrations are in ppm; specific conductance is in micromhos/Cm^2 at 25°C

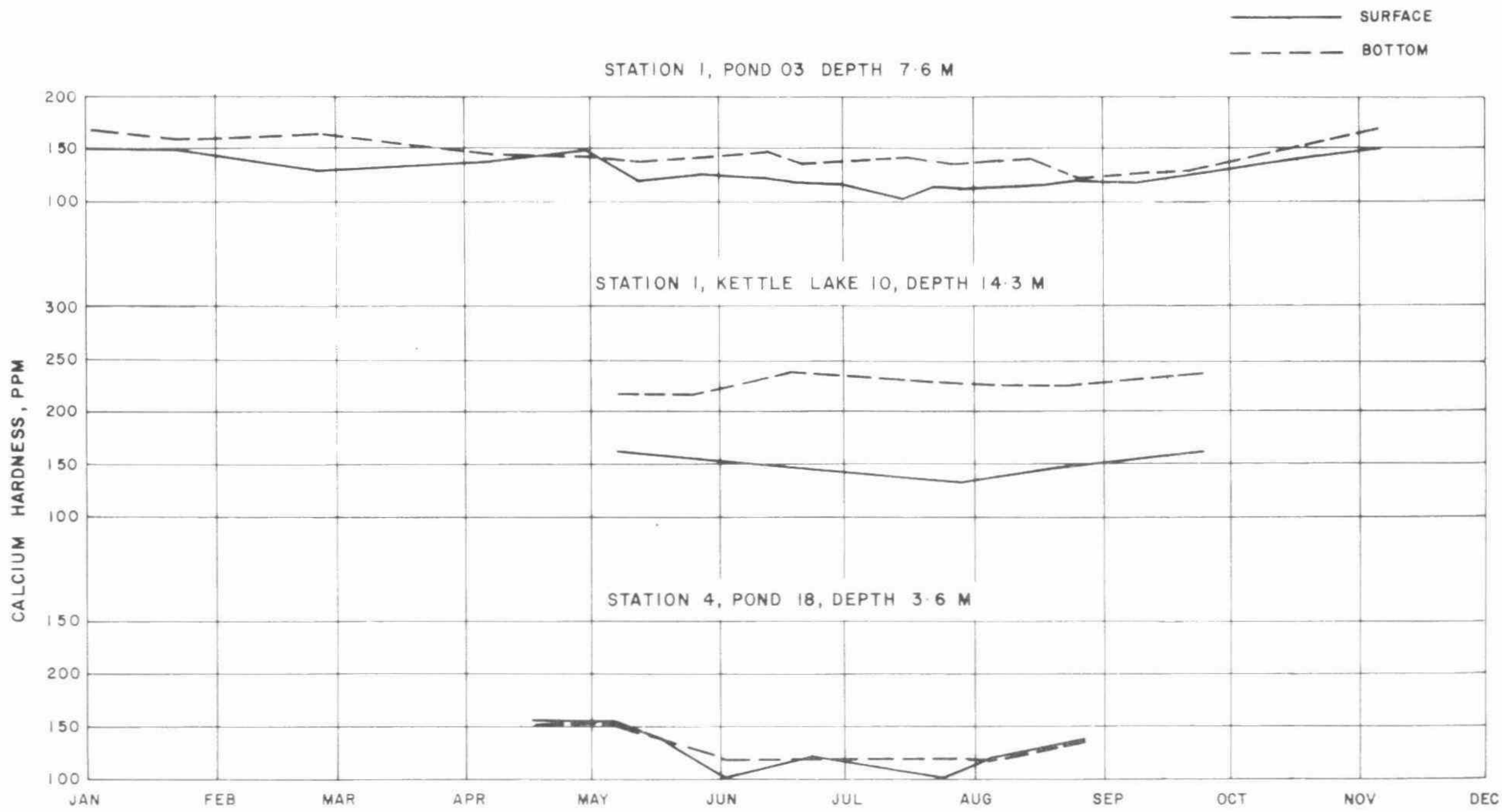

FIGURE 14. Typical seasonal trends in calcium hardness in surface and bottom waters of deep, intermediate and shallow impoundments, based on 1970 data.

Average calcium hardness ranged from 40 to 247 ppm in surface layers and from 40 to 260 ppm in bottom layers. Differences between the top and bottom strata were greatest in the deeper kettle lakes.

When the impoundments are arrayed in ascending order of the total hardness of their surface waters, as in Table 5, three groups can be distinguished. The first group comprises the smaller kettle lakes (01, 02, 37) and pond # 36, which have low hardness (52 to 120 ppm). A common feature of these impoundments is the lack of continuous flushing; tributary streams are either intermittent or lacking. In addition, these lakes have very small watersheds (20 - 25 ha) from which they receive allochthonous matter.

The second group contains the larger kettle lakes (05,10, 11, 20, 26) and several on-stream ponds (15, 17, 18, 28, 29, 31, 32 and 33) having moderately hard water. Total hardness of surface waters range from 128 to 224 ppm. The larger on-stream dams (15, 17, 18, 28) are subject to continuous flushing but summer outflow is much reduced or absent in the kettle lakes and smaller ponds. Most watershed areas for this group are between 49 and 2,095 ha but pond 17, a large flood control impoundment, has a drainage basin of about 16,000 hectares.

In the third group are the two quarry ponds (34 and 35) and two small on-stream ponds (16 and 19), the surface waters of which have total hardnesses from 248 to 292 ppm. Quarry pond # 34 is fed by a small intermittent tributary of the Humber River and has a watershed of 346 ha. Quarry pond # 35 has a negligible surface drainage while ponds # 16 and 19 are supplied from a large aquifer.

Specific conductance and total dissolved solids

The average specific conductance for surface waters in these impoundments ranged from 82 to 592 micromhos/cm^2 (at 25°C) while values for the bottom layers ranged from 82 to 638 micromhos/cm^2 (Tables 5 and 6). Highest values were found in the larger kettle lakes (10, 11, 05, 26), the two quarry ponds (34, 35) and in two ponds (16, 19) located on a large aquifer. The values also varied with the seasons (Figure 15).

Since it is usually easier to measure specific conductance with a conductivity bridge than to determine total dissolved solids gravimetrically, the latter is sometimes estimated from the former on the basis of an appropriate regression line. Statistical analyses of the present data give the line: $Y = -17.0 + 0.0769\ X$, where X is the specific conductance in micromhos/cm^2 at 25°C and Y is the content of total dissolved solids in ppm. The coefficient of correlation is 0.937 and the standard error of estimate is 42.7 ppm.

Total alkalinity and pH

Total alkalinity varied widely from one impoundment to another. In surface layers the average total alkalinities, expressed as ppm $CaCO_3$ ranged from 60 to 223 while in bottom layers they ranged from 60 to 274 (Tables 5 and 6). As with hardness, total alkalinity declined in the surface layers and increased in the bottom layers during the summer (Figure 16). Moreover, the difference between surface and bottom values was again greatest in the kettle lakes at the height of mid-summer stratification.

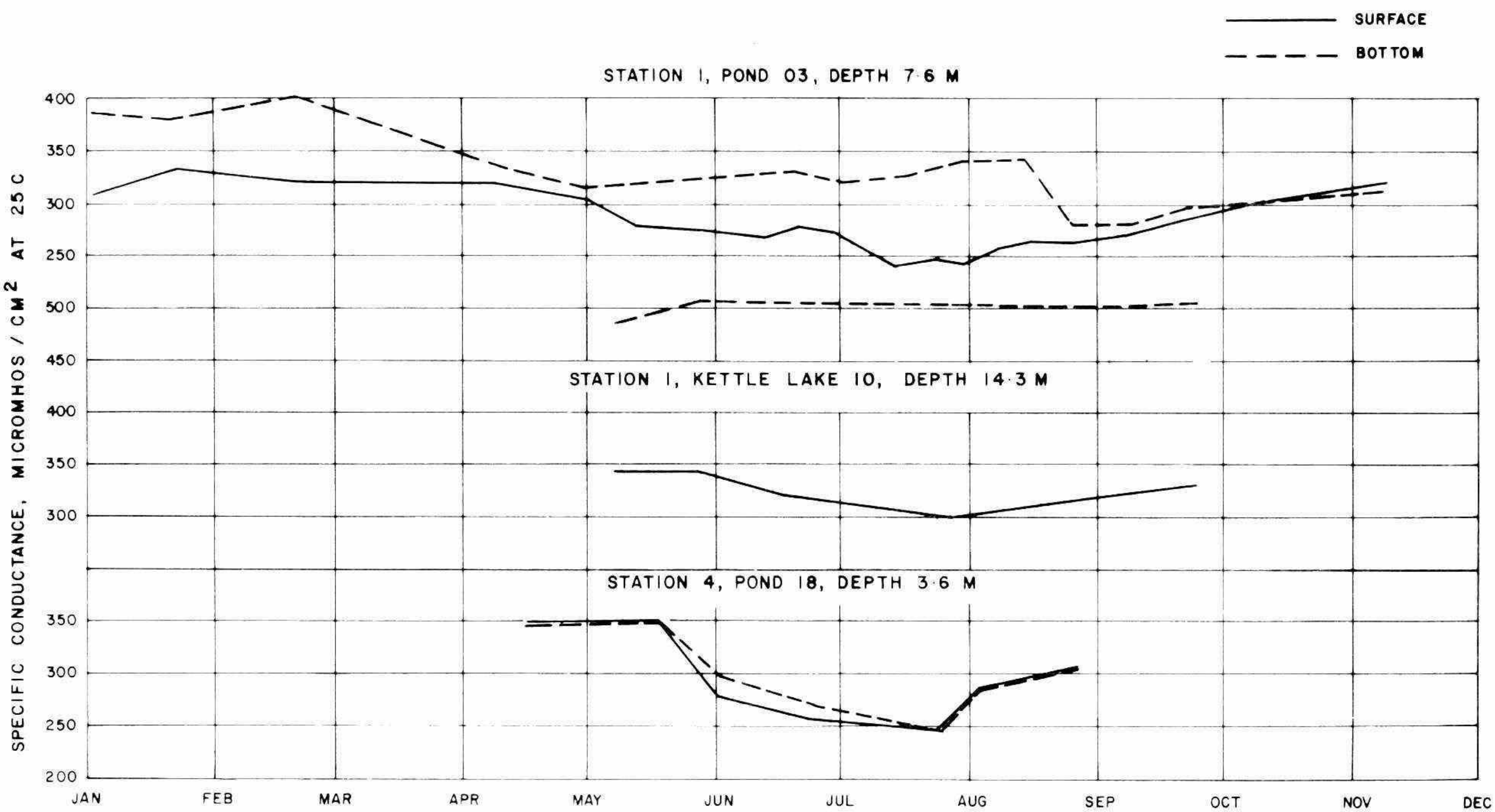

FIGURE 15. Typical seasonal trends of specific conductance in the surface and bottom waters of deep, intermediate and shallow impoundments, based on 1970 data.

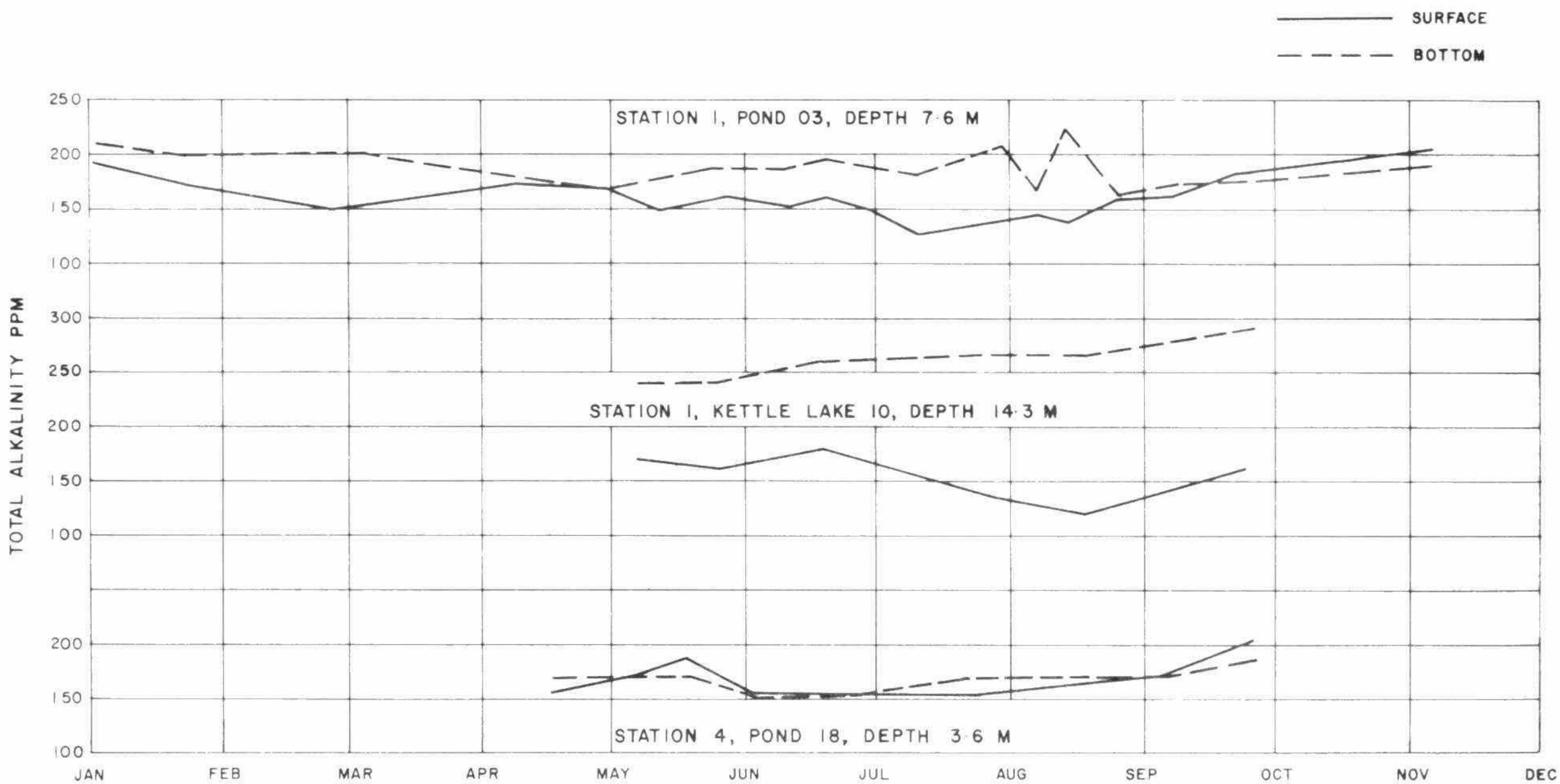

FIGURE 16 Typical seasonal trends of total alkalinity in the surface and bottom waters of deep, intermediate and shallow impoundments, based on 1970 data.

As the plants remove the free carbon dioxide from the water by photosynthesis, calcium bicarbonate is converted to calcium carbonate and the latter being less soluble, precipitates. Where the carbonate precipitates over a deep, strongly stratified basin, it may be reconverted to bicarbonate in the hypolimnion and redissolve, since the hypolimnilal waters in such basins usually contain excess carbon dioxide. On the other hand, where the calcium carbonate precipitates in the littoral zone of a lake, or in a shallow pond exhibiting little stratification, only a small portion redissolves. Instead most of it becomes incorporated with the bottom sediment as marl when the aquatic plants decompose.

Generally speaking, the waters were neutral to slightly alkaline (Tables 5 and 6). Average pH for surface waters in most of the impoundments ranged from 7.1 to 8.4. Readings for bottom waters tended to be slightly lower, especially in the kettle lakes and quarry ponds when considerable amounts of carbon dioxide accumulated in the hypolimnion.

A notable exception was found in lake # 37 where the pH for top and bottom waters averaged 6.9 and readings as low as 6.1 and 6.3 occurred on one occasion. One reading of 6.8 was also recorded in the bottom of the smallest kettle lake # 01. In both of these lakes there were mats of partially decomposed plant matter on the bottom.

Calcium and magnesium

On the average, calcium comprised about 20% of the total dissolved solids in these waters and the two values were closely correlated. The coefficient of correlation was equal to 0.924 and the regression line was: $Y = 33.3 + 0.302\ X$, where Y is the concentration of calcium in ppm and X the concentration of total dissolved solids in ppm. The standard error of estimate was 12.2 ppm.

Average concentrations of calcium ranged from 20 to 74 ppm at the surface of the impoundments and from 17 to 94 ppm near the bottom (Tables 7 and 8).

Magnesium averaged about 4% of the total dissolved solids. Concentrations ranged from less that 1 to 21 ppm in the surface waters and from 2 to 29 in the bottom layers (Tables 7 and 8).

Iron, manganese and copper

With one exception, average concentrations of iron in the surface waters of the impoundments were less than 1.0 ppm (Table 7). A single sample from quarry pond # 34 had a concentration of 1.10 ppm. Average iron content of bottom waters was also less than 1.00 ppm in most instances, though greater values were found in five of the impoundments (Table 8). The highest concentrations, namely 3.32 ppm and 4.05 ppm occurred in quarry pond 34 and mill pond 15, respectively.

In most of the impoundments, concentrations of manganese were less than 1.0 ppm in both the surface and bottom water (Tables 7 and 8). Manganese was not detected in surface samples from seven of the impoundments and in bottom samples from three impoundments. However, average concentrations as high as 1.60 and 4.40 ppm were found in bottom waters of pond # 19 and kettle lake # 05, respectively.

Analyses for copper were carried out because this element is toxic to fish at low concentrations and because copper sulphate and other copper compounds are commonly used as algicides. Moreover, copper residues can accumulate in sediments. In most instances copper was not found in surface

TABLE 7: MEAN CHEMICAL CONCENTRATIONS (PPM) IN SURFACE WATERS OF THE IMPOUNDMENTS SAMPLIED IN 1970, BASED ON ANALYSES CARRIED OUT BY THE LABORATORIES BRANCH, MINISTRY OF THE ENVIRONMENT.

Impound-ment Code	Number of Samples	Total Hard-ness	TDS	Tot. P	Sol P	KJEL N	NH_3	NO_2	NO_3	Ca	Mg	Fe	Mn	Cu	SiO_2	SO_4	Cl
01	1	52	90	.057	.004	1.1	.08	.003	.01	20	<1	.25	.00	.00	.4	12	9
37	8	53	100	.030	.006	.69	.63	.002	<.01	20	1.	.27	.12	.00	5.5	5	4
02	3	114	225	.016	.001	.46	.02	.001	.01	36	7	.05	.00	.00	2.5	6	26
36	1	120	160	.02	.013	.24	.04	.007	.01	34	8	.10	.00	.00	.75	12	9
20	1	128	220	.022	.004	.56	.06	.002	.01	34	11	.05	.01	.00	7.0	19	7
05	3	136	183	.019	.008	.56	.06	.001	<.01	45	6	.20	.03	.00	1.45	17	6
03	4	159	200	.041	.008	1.3	.69	.013	.17	52	5	.37	.02	.00	5.65	13	5
11	2	168	260	.01	.002	.57	.07	.07	<.01	62	5	.05	.03	.00	8.0	26	7
10	2	174	250	.060	.002	.68	.04	.008	.02	63	5	.05	.01	.00	4.0	26	8
28	8	180	241	.026	.003	.50	.04	.005	.11	53	19	.24	.03	.00	9.6	24	5
29	3	185	254	.065	.018	.61	.04	.005	.04	65	14	.20	.11	.018	6.45	29	5
34	1	194	350	.04	.018	.70	.07	.011	.02	58	15	1.10	.00	.00	4.6	64	35
18	4	203	269	.041	.005	.57	.09	.031	1.91	54	24	.14	.03	.00	9.3	21	8
33	3	208	265	.014	.003	.50	.09	.017	.76	54	15	.12	.04	.00	7.56	24	9
15	2	211	280	.047	.007	.43	.14	.001	<.01	54	18	.15	.00	.00	9.16	22	7
31	4	216	290	.039	.010	.49	.04	.013	1.10	60	21	.24	.03	.02	6.8	24	23
26	1	216	300	.012	.004	.58	.01	.002	.01	66	12	.10	.00	.00	4.3	19	8
32	4	221	289	.019	.009	.55	.13	.018	.99	59	20	.12	.03	.00	9.6	24	9
17	2	224	365	.08	.005	.88	.08	.20	.07	75	8	.52	.13	.00	5.5	29	45
16	2	259	390	.050	.019	.55	.08	.011	.07	85	11	.62	.15	.00	13.7	33	26
35	3	291	473	.016	.010	.29	.10	.009	.83	88	17	.25	.03	.02	1.13	136	31
19	2	292	495	.055	.005	.79	.15	.034	.18	82	19	.71	.93	.00	8.2	91	38
34	1	248	390	.016	.004	.67	.06	.023	.24	74	15	.00	.00	.00	3.6	62	41

TABLE 8: MEAN CHEMICAL CONCENTRATIONS (PPM) IN BOTTOM WATERS OF THE IMPOUNDMENTS SAMPLED IN 1970, BASED ON ANALYSES CARRIED OUT BY THE LABORATORIES BRANCH, MINISTRY OF THE ENVIRONMENT.

Impoundment Code	Number of Samples	Total Hardness	TDS	Tot P	Sol P	Kjel N	NH_3	NO_2	NO_3	Ca	Mg	Fe	Mn	Cu	SiO_2	SO_4	Cl
37	3	55	107	.096	.004	1.6	.01	.002	.01	17	1.7	.90	.07	.027	.3	5	4
01	1	56	90	.034	.004	1.2	.23	.003	.01	24	5	.25	.19	.00	.5	11	6
03	4	163	300	.063	.019	1.6	.84	.016	.186	53	7	1.00	.11	.00	6.8	10	5
02	2	172	230	.235	.028	2.2	.50	.502	.01	56	11	.75	.00	.01	3.8	6	22
20	1	178	240	.21	.08	1.7	1.6	.004	.01	69	1.4	.10	.94	.02	10.3	17	6
28	8	180	241	.052	.004	.30	.05	.005	.074	48	22	.14	.02	.007	10.4	25	5
29	4	188	266	.089	.027	.56	.04	.006	.028	68	13	.78	.23	.062	7.0	29	5
05	3	202	256	.616	.396	6.3	3.76	.004	.013	65	27	.22	4.40	.00	7.1	16	6
18	4	203	270	.037	.004	.42	.11	.030	1.15	51	25	.28	.04	.01	8.5	18	8
33	3	218	278	.021	.006	.47	.10	.024	.56	54	17	.17	.04	.022	8.2	26	9
31	4	220	291	.032	.012	.64	.04	.012	1.22	70	16	.20	.03	.19	7.3	25	23
15	2	223	290	.161	.095	1.2	.01	.011	.01	53	9	4.05	.03	.025	12.8	23	6
26	1	232	305	.066	.041	1.3	.65	.002	.01	74	11	.12	.28	.00	8.1	19	8
32	4	237	315	.066	.031	1.5	.62	.022	.51	70	19	.29	.40	.027	13.4	24	10
17	2	242	400	.189	.040	2.1	.52	.054	.135	75	13	1.40	.98	.075	8.5	24	41
34	1	248	400	.073	.037	.54	.08	.017	.01	77	17	3.32	.00	.00	5.1	58	32
34	1	256	400	.02	.004	.60	.13	.032	.42	55	29	.20	.00	.00	3.2	68	40
10	2	257	360	.33	.235	2.9	2.25	.005	.008	90	8	.17	.71	.00	12.7	30	14
11	3	264	365	.375	.175	3.8	2.35	.005	.01	97	6	.32	.59	.00	7.9	29	13
16	2	273	390	.080	.055	.12	.61	.012	.10	88	12	.85	.24	.335	13.2	32	26
35	3	301	482	.025	.007	.43	.24	.098	.07	94	16	.62	.69	.006	2.3	132	31
19	2	305	490	.759	.501	3.8	2.84	.025	.07	92	18	1.60	1.73	.00	8.7	104	39
06	2	161	245	.035	.013	.97	.38	.043	.20	51	8	.77	.47	.15	4.8	12	21

waters. Exceptions were three impoundments in which concentrations of borderline significance (0.018 to 0.020 ppm) occurred. In contrast, copper was found in the bottom waters of 13 impoundments at concentrations ranging from 0.007 to 0.335 ppm (Table 8).

Phosphorus and nitrogen

In most instances the phosphorus concentrations in bottom waters were significantly higher than those in surface layers (Tables 7 and 8). Average concentrations of total phosphorus ranged from 0.010 ppm to 0.065 ppm in the surface layers and from 0.020 to 0.759 ppm in the bottom waters. Soluble phosphorus ranged from 0.002 to 0.019 ppm in surface water and from 0.004 ppm to 0.501 ppm in the bottom layers. Under anoxic conditions iron phosphorus complexes which have been deposited in the bottom sediments may redissolve as the iron changes from the ferric to ferrous form (Brydges, 1970). This would account for the higher concentrations of phosphorus in the bottom layers during summer and winter stratification. At spring and autumn turn-overs, this iron and phosphorus may be brought to the surface and made available to plants in the euphotic zone.

The concentrations of total and soluble phosphorus found in the present study are comparable to those reported in other surveys for relatively unpolluted upstream reaches of the Credit, Humber, Don, Rouge and Duffin river systems (OWRC report).

Concentrations of Kjeldahl nitrogen were higher in the surface water samples than in the bottom samples in most instances (Table 7 and 8). Surface concentrations averaged from 0.24 to 1.3 ppm and bottom samples averaged from 0.12 to 6.3 ppm. Higher concentrations of Kjeldahl nitrogen were usually found in impoundments where anoxic conditions developed during summer stratification.

Concentrations of ammonia ranged from 0.01 to 0.69 ppm in surface layers and from 0.05 to 3.76 ppm in bottom waters (Table 7 and 8). Highest concentrations were found in bottom samples from impoundments in which anoxic conditions developed during summer stratification (kettle lakes 05, 10, 11, 20, 26 and ponds 13 and 19).

Average concentrations of nitrites ranged from 0.001 to 0.070 ppm in surface waters and from 0.004 to 0.098 ppm in bottom strata. Nitrates averaged from less than 0.01 to 1.91 ppm in surface waters and from less than 0.01 to 1.22 ppm in bottom samples. The highest concentrations of nitrates were found in samples from the large ponds 18 and 31 which were subject to considerable flushing and hence were well aerated.

Silicate, sulphate and chloride

Concentrations of silicate ions in surface waters averaged from 0.40 to 9.6 ppm except for one impoundment where two samples averaged 13.7 ppm (Table 7). In bottom samples, the average concentrations ranged from 0.36 to 13 ppm (Table 8).

In most impoundments sulphate concentrations ranged from 5 to 33 ppm for both surface and bottom waters (Tables 7 and 8). However, in the two quarry ponds (34 and 35) and in pond # 19 located on a large aquifer, surface concentrations ranged from 64 to 136 ppm while bottom concentrations ranged from 58 to 132 ppm.

Average chloride concentrations were similar in surface and bottom waters and ranged from 4 to 41 ppm (Tables 7 and 8).

Chemistry of the sediments

Total quantities of nitrogen, phosphorus, iron, manganese and percent loss on ignition in sediment samples collected from several impoundments during 1969 and 1970 are summarized in Table 9. The methods and results were previously reported by Brydges (1970).

Loss on ignition (LOI), which is a measure of the organic content of the sediments, ranged from 1.0% in impoundment #06 to a maximum 59.2% in #37. The latter impoundment is a large shallow lake, densely populated with aquatic plants which have, over the years contributed vast quantities of organic matter to the bottom. The fact that a large portion of impoundment #31 was dredged in the fall of 1969 accounts for the drastic decrease from 10.2% in 1969 to 1.4% in 1970 in the organic content of the sediments.

The nitrogen content of the sediments varied between 0.55 and 20.0 mg/g dry weight. Generally, Kjeldahl nitrogen concentration in the sediments was proportional to the percentage loss on ignition, indicating that nitrogen was in organic form.

The lowest phosphorus concentration (0.29 mg/g dry weight) was obtained from sediment collected at a shallow water station in pond #19. In contrast, the maximum concentration of 2.0 mg/g dry weight was recorded for a sample collected from the deep water station in kettle lake #10. In impoundment #31, the notable decline in phosphorus levels in 1970 can be attributed to the dredging. No relationship was found between phosphorus concentrations and the Kjeldahl nitrogen or loss on ignition values, indicating that phosphorus is present mainly in an inorganic form. Iron concentrations ranged from 7.0 to 36.9 mg/g and were proportional to total phosphorus concentrations, suggesting that an inorganic mechanism is most important in binding phosphorus in sediments (Brydges 1970).

TABLE 9: TOTAL CONCENTRATIONS OF NITROGEN, PHOSPHORUS, IRON AND MANGANESE IN SEDIMENT SAMPLES COLLECTED DURING 1969 AND 1970. ALL CONCENTRATIONS ARE GIVEN IN mg/g, WHILE THE LOSS ON IGNITION (LOI) IS EXPRESSED AS A PERCENTAGE OF THE DRY WEIGHT.

Impoundment Code	DATE	% LOI	N	P	Fe	Mn
02	1969	12.8	6.0	1.30	24.0	0.97
	1969	55.7	18.0	0.92	15.0	0.62
	1970	26.8	5.3	0.38	8.2	0.12
	1970	56.9	20.0	0.95	22.0	0.25
03	1969	5,5	2.0	1.0	20.0	0.55
	1969	28.2	15.0	1.7	35.0	1.20
	1969	6.4	1.8	0.55	19.0	0.38
05	1969	14.2	10.0	1.6	29	1.2
	1969	28.3	14.0	0.95	17	0.49
	1969	13.2	11.0	1.3	28	0.30
	1970	25.5	12.0	0.68	16	0.44
	1970	16.1	5.4	0.62	14	0.50
	1970	16.1	5.2	0.72	14	0.44
06	1969	1.0	0.97	0.59	14	0.35
	1970	7.0	2.3	0.33	19	0.6
	1970	1.8	0.55	0.65	16	0.39
10	1969	19.8	14	1.6	25	0.67
	1969	18.4	16	1.2	9.5	0.26
	1969	20.7	14	2.0	29	0.40
15	1969	15.0	4.8	1.3	17	0.55
	1969	7.2	3.3	0.94	19	0.28
	1969	6.7	4.3	1.4	31	0.81
16	1969	10.1	5.7	1.4	31	0.97
	1969	6.2	4.1	1.1	21	0.19
	1970	14.3	6.0	0.82	9.3	0.36
	1970	17.6	4.3	0.82	10.0	0.65
17	1969	1.8	0.95	0.78	19	0.49
	1969	4.3	1.9	0.88	24	0.65
18	1969	21.3	7.8	0.98	14	0.28
	1969	35.1	10.0	1.2	19	0.50
	1969	17.7	8.3	1.3	15	0.49
	1970	18.7	14.5	1.15	16.5	0.64

TABLE 9 - continued....

Impoundment Code	DATE	% LOI	N	P	Fe	Mn
19	1970	4.03	1.25	0.29	24	1.10
	1970	12.5	4.08	0.81	32	1.90
20	1970	40.8	6.3	0.48	14.0	0.44
	1970	45.7	10.3	1.2	23.0	1.00
27	1969	12.3	6.6	1.4	25	0.83
29	1969	7.8	4.4	1.3	22	0.53
	1970	8.9	2.7	0.9	21.0	0.65
31	1969	10.2	3.6	0.94	17.0	0.58
	1970	1.4	0.5	0.31	21.2	0.33
32	1969	22.9	8.1	1.3	18	0.71
	1970	25.0	8.3	0.80	36.9	1.3
36	1970	6.4	0.76	0.31	17.0	0.36
37	1970	59.2	15.0	0.79	7.0	0.12

TABLE 10: CONCENTRATIONS OF NITRATE, AMMONIA, TOTAL NITROGEN, TOTAL PHOSPHORUS, SOLUBLE PHOSPHORUS, IRON, MANGANESE AND CALCIUM RELEASED FROM THE SEDIMENTS UNDER AEROBIC AND ANAEROBIC CONDITIONS, (MICROGRAMS/GRAM OF SEDIMENT). (DATA FROM BRYDGES, 1970)

AEROBIC CONDITIONS

Impoundment Code	NO_3	NH_3	N	TP	SP	Fe	Mn	Ca
02	9	140	220	57	100	140	5	7,100
	5	13	80	20	5	70	0	11,000
03	8	30	65	14	11	135	3	2,400
	4	85	680	130	15	240	5	12,000
	4	10	30	7	2	30	0	-
05	11	260	1040	90	68	170	7	1,800
	4	160	510	46	30	110	0	8,300
	7	20	320	31	10	120	0	7,000
06	5	25	50	17	25	430	4	1,350
10	17	300	350	105	160	285	2	9,700
	17	170	580	-	35	65	5	14,000
	20	700	1030	190	230	220	7	13,500
15	4	16	105	34	20	90	4	3,650
	2	2	25	9	4	60	2	3,000
	3	70	175	37	30	230	5	4,450
16	6	80	155	33	26	180	4	440
	5	70	-	-	20	200	1	-
17	7	62	75	27	12	460	4	2,100
	2	53	97	44	14	310	5	1,700
18	3	6	170	17	2	0	9	6,100
	7	14	205	16	4	13	7	6,300
	1	2	130	12	1	10	0	2,500
27	17	45	140	11	11	70	1	3,650
29	2	9	54	13	7	140	4	4,570
31	3	37	85	14	7	120	4	2,100
32	10	11	290	40	11	100	0	5,770

TABLE 10 - continued

ANAEROBIC CONDITIONS

Impound-ment Code	NO_3	NH_3	N	TP	SP	Fe	Mn	Ca
02	8	170	170	145	133	430	57	6,400
	6	63	190	44	40	140	35	10,000
03	3	50	100	40	35	180	20	2,000
	3	370	600	120	55	790	50	7,500
	1	20	80	19	12	80	3	-
05	9	360	1075	280	230	220	120	7,700
	4	203	550	70	64	70	7	8,300
	12	140	1000	60	50	250	0	6,000
06	10	65	60	-	56	645	9	1,650
10	8	370	450	180	280	235	35	8,400
	12	260	450	44	40	130	7	12,000
	13	680	960	270	340	240	7	11,500
15	3	50	185	70	80	130	25	3,150
	6	20	75	33	25	130	10	2,000
	3	110	260	95	95	145	20	4,000
16	3	120	300	150	160	220	37	3,500
	5	90	-	-	50	320	40	-
17	7	65	65	43	37	430	10	2,200
	7	73	110	32	25	480	15	1,800
18	-	50	310	17	6	10	20	4,300
	12	90	540	50	37	63	53	3,900
	-	30	160	42	6	35	6	1,800
27	1	80	235	-	45	180	25	2,700
29	3	30	70	35	24	120	30	3,000
31	4	50	140	30	21	170	38	900
32	3	140	430	60	30	120	30	3,800

Since in nature, sediments are subjected to both aerobic and anaerobic conditions, which are known to affect sediment-water exchange, the 1969 sediment samples were extracted with water under both conditions, and the amounts of various elements released into the water were measured.

Quantities of nitrate ammonia, total kjeldahl nitrogen, total phosphorus, soluble phosphorus, iron, manganese and calcium released into the water under aerobic and anaerobic conditions are shown in Table 10. Similar quantities of ammonia nitrogen were released under both aerobic and anaerobic conditions suggesting that nitrogen is re-cycling as a result of the breakdown of organic matter. With two exceptions, negligible quantities of phosphorus were re-cycled, under aerobic conditions. However, under anaerobic conditions soluble phosphorus released into the water was proportional to the total phosphorus content in the sediment. Lakes #05 and 10 were found to release similar amounts of phosphorus under both aerobic and anaerobic conditions.

The plant communities: macrophytes

Distribution and abundance

The distribution and abundance of aquatic plants have been attributed to temperature, depth, light penetration, substrate characteristics and water chemistry (Boyd 1971; Pearsall 1920; Peltier and Welch 1970; Moyle 1945). Areas of suitable substrate for plant growth were evident in all the impoundments studied, consisting primarily of marl, sand and gyttya in the kettle lakes and mixtures of silt and organic muck in the remaining ponds. However, in the kettle lakes, growth was restricted to the littoral zone, likely as a result of light limitation.

Plants representing 10 genera were collected from the 23 impoundments and within these genera, 18 species were identified with certainty. Speciation of the stoneworts, *Chara spp.*, was not attempted. Distribution and relative abundance of each species are detailed in Table 11.

TABLE 11. DISTRIBUTION AND RELATIVE ABUNDANCE OF AQUATIC PLANTS IN 23 IMPOUNDMENTS

SPECIES	IMPOUNDMENT CODE																						
	01	02	03	05	06	10/11	15	16	17	18	19	20	26	27	28	29	31	32	33	34	35	36	37
hara spp.	+	++	+	++	++	++	+	++			++	+		++	++		+	++	++			++	++
otamogeton pectinatus L.		++		++	+	+	+	+	+	++			++	+	++	+	++						
otamogeton foliosus Raf.			+				++	++		+					++			++		+			
otamogeton nodosus Poir.						+																	
otamogeton strictifolius Benn.			+	++							++												
otamogeton natans L.					+								++				+						
otamogeton amplifolius Tuckerm.	++																						++
otamogeton epihydrus Raf.													+										
otamogeton obtusifolius Mert. & Koch.												+											
otamogeton zosteriformis Fern.												+	+										
otamogeton crispus L.									++														
ajas flexilis (Willd.)				+			+	+				++							+			++	
lodea canadensis (Michx.)		++														++		++	++				
tricularia vulgaris L.				+		++							+										+
eratophyllum demersum L.						+			+														
eratophyllum echinatum Gray.			++	+								++											
yriophyllum exalbescens Fernald.																		+	++				
anunculus sp.													+										
olygonum natans Eat.			+	+									+				+						
olygonum coccineum Muhl.									++														
repanocladus							+	++						++									
emna Minor L.									+					+				+					+

\+ Present

++ Abundant

The stoneworts were extremely common, occurring in 17 of the 23 impoundments. While they occasionally occurred mixed with other species, particularily the pondweeds, they generally formed dense monospecific beds where no other plants could gain a foothold. Fosberg (1965) found that luxuriant growths of charophytes were typical in oligotrophic lakes while dense beds of charophytes interspersed among the phanerograms were common in moderately eutrophic lakes. The charophytes are known to thrive on various types of sediment including marl deposits, sand and clay.

The pondweeds _Potamogeton spp._, were found in all but one impoundment and were frequently associated with dense beds of charophytes. Ten species were identified and of these, the most common was sago pondweed, _P. pectinatus_. This species, described by Sculthorpe (1967) as truly cosmopolitan, was the dominant plant in one impoundment, abundant in five and present in seven others. Sago appeared to thrive only in heavily silted areas of the ponds. The first young shoots of this perennial plant were usually observed during the month of May. The plants matured and formed seeds during July, following which they turned brown and dropped to the bottom. New young shoots were observed again during late August and early September.

P. foliosus, a relatively common species, was prominent in four and present in three ponds. In all instances it was associated with _Chara spp._, and/or _P. pectinatus_. _P. nodosus_ was present in only one impoundment, associated with the above species, while _P. amplifolius_ was prominent in lakes #37 and #01. _P. natans_ was observed growing in the shallow areas of three impoundments, rooted in rich organic substrate. Of the remaining four species, _Potamogeton epihydrus_, _P. obtusafolius_, _P. zosteriformis_ and _P. crispus_ only the latter was abundant in one enriched impoundment. This species introduced to North America during the early 1800's, is known to tolerate waters highly enriched by urban wastes (Muenscher 1944; Victorin 1947; McCombie and Wile 1971).

Bushy pondweed, Najas flexilis occurred in relatively insignificant amounts in four impoundments but was abundant in two others. This plant formed long slender stems in deep waters and short compact bushy plants in shallow waters and thrived both on soft organic and marl substrates. This species is widespread in ponds and lakes throughout North America, ranging from about 50° to about 30° North (Sculthorpe, 1967; Muenscher, 1944).

Elodea canadensis was extremely prominent in one kettle lake and three stream-fed ponds, growing both in marl and fine organic substrates. It is indigenous to North America and extremely widespread, ranging through 25° to 30° latitude and covering the entire longitudinal span of the continent (Sculthorpe, 1967).

Utricularia vulgaris was found in four impoundments and was particularly prominent in a shallow channel connecting kettle lake basins #10 and 11 and adjacent to a large stand of Typha latifolia in lake #37. The vegative body of this carnivorous plant consists of an elongated branched axis with numerous delicate leaves, some of which bear small hollow bladder-like traps. These bladders are used to engulf the prey, usually crustaceans or aquatic larvae. Plants of the genus Utricularia are rootless, although several species become anchored in the substrate by means of modified branches of the axis (Sculthorpe, 1967).

Two species of free-floating plants of the genus Ceratophyllum were identified. C. demersum was present in two impoundments, while C. echinatum was abundant in two and present in one other. Both species are widespread and common in ponds, shallow lakes and sluggish streams and are frequently the dominant aquatics in temporary or newly made ponds in which the water is rich in organic matter and dissolved materials (Muenscher, 1944; Pearsall, 1920).

Myriophyllum exalbascens was found in only two impoundments, growing to a depth of 3 meters. This species has become widespread in North America during the last ten years, infesting waterways and causing numerous problems. It is a perennial submersed plant that spreads rapidly by both vegetative reproduction and seed but its most effective method of dissemination is by fragmentation.

Two species of smartweed were identified; Polygonum natans and P. coccineum. The former was present in four impoundments while the latter was prominent in one highly enriched pond.

Drepanocladus, an aquatic moss, occurred in three impoundments in varying degrees of abundance, and generally formed dense, impenetrable beds, interspersed among the charophytes.

The surface-floating plant, Lemna minor was found in only four impoundments in relatively minor quantities.

Standing crops

In seven impoundments, the standing crop of the macrophytes was determined by collecting all plant material growing within randomly placed 1/4 m^2 quadrats. Sampling was undertaken in late July and in August when the plants were considered to have attained their seasonal maxima. Since the impoundments ranged widely in size and percent cover (17% to 100%), both weedy, weed-free and partially bare areas were sampled to provide average values for each study area.

In a pure stand of Chara spp., the maximum fresh weight obtained from a single quadrat was 2,110 g. Rickett (1924) recorded a maximum weight of 2,700 g. per 1/4 m^2 for Chara spp., in Green Lake, Wisconsin. Maximum dry weights per quadrat for Chara spp., Elodea canadensis and Potamogeton

TABLE 12: STANDING CROPS OF MACROPHYTES EXPRESSED AS GRAMS OF DRY WEIGHT PER SQUARE METRE

Impoundment Code	Ave. dry wt. (gms) per m^2	Species Present	Remarks
32	358	E.canadensis, Chara spp. M.exalbescens, P.foliosus	Elodea formed 67.6% of the total crop and Chara spp. formed 16.3% P. foliosus comprised 13.9% of the total and M.exalbescens formed the remainder.
29	356	E.canadensis, P.pectinatus	Elodea was extremely abundant forming 94.9% of the total crop while P.pectinatus formed the remaining 5.1%.
37	318	Chara spp. P.amplifolius, U.vulgaris	Mainly composed of Chara spp. (77.3%). P.amplifolius comprised 22.5% of the total while U.vulgaris was present in negligible quantities.
05	317	Chara spp. P.pectinatus, P.strictifolius, N.flexilis, U.vulgaris, C.echinatum, P.natans.	Largely composed of Chara spp. (54.7%). P.pectinatus formed 34% of the crop while P.strictifolius formed 11% of the total. The remaining four species comprised less than 1%.
31	198	P.pectinatus, Chara spp. P.natans, Poly. natans.	Virtually entirely composed of P.pectinatus. The remaining three species formed less than 1% of the total.
10/11	177	Chara spp. U.vulgaris, P.nodosus, P.pectinatus, C.demersum.	Chara spp. formed 90.9% of the total crop. U.vulgaris formed 7.9% while the remaining species formed the balance.
18	48	P.pectinatus, P.foliosus.	Virtually entirely composed of P.pectinatus. P.foliosus formed less than 1% of the total crop.

pectinatus were 275, 180 and 175 grams respectively.

Standing crops of macrophytes expressed as average dry weights of plant material (g/m^2) are given in Table 12. In the two most productive ponds, dense beds of hydrophytes covered the entire bottom while in the least productive impoundment, only scattered patches were evident. The maximum standing crop of 358 g/m^2 was obtained from pond #32 which supported a total dry weight of 4,659 kg of plant material. In the smaller impoundment, #29, the standing crop was 356 g/m^2 and the total dry weight of plant material was 1,425 kg while in the relatively unproductive pond #18, the total crop was 1,570 kg.

Although submersed and floating-leafed aquatic plants provide a visual impression of luxuriance, when judged by quantitative criteria, they are less productive than emergent aquatic plants owing to their high water content. According to Boyd (1971) submersed and floating-leafed species usually have standing crops of less than 500 g/m^2 dry weight. Emergent plants generally have much higher standing crops, ranging from 500 to 1500 g/m^2, although values in excess of 2,000 g/m^2 have been recorded.

Chemical composition of some aquatic plants

Seven species of aquatic plants were collected from several impoundments and analyzed for nitrogen, phosphorus, iron, manganese, calcium, magnesium and loss on ignition and the results expressed as a percent of the dry weight. All values for N, P, Fe and Mn were corrected utilizing the % LOI values to compensate for the marl content of the samples (Appendix I) and the ash weight was calculated as the residue of the loss on ignition.

The average percent water loss was calculated for each species and is tabulated as follows:

Chara spp	83.8
Potamogeton strictafolius	84.4
Potamogeton pectinatus	85.6
Drepanocladus	85.4
Utricularia vulgaris	87.2
Elodea canadensis	88.0
Najas flexilis	89.6

With the exception of *Drepanocladus*, these values are somewhat lower than the values recorded by Ricket (1924) in Green Lake, Wisconsin. He reported an average percent moisture loss of 84.9% for *Chara spp*., 81.1% for *Drepanocladus*, and 92.9% for *Elodea candensis.* Fish and Will (1966) obtained a 92.1% average water loss for *Elodea canadensis* growing in the oligotrophic Lake Okataina and a 93.1% loss for Elodea growing in the highly enriched Lake Rotorua, New Zealand.

Conversely, the dry weights ranged between 12 and 16.2% of the fresh weight, falling within the 5 to 20% range outlined by Westlake (1965) for most submerged and soft emergent plants. Both the high percentage of water loss and corresponding low dry weights were rather surprising since marked deposits of carbonate compounds were observed on all vegetative structures of the plants. Although some of these marl deposits were removed during washing, substantial deposits remained on the plant structures. Westlake (1965) reported that where calcareous deposits are present, the dry weight of the plant may approach 25% of the fresh weight. These carbonate deposits, which commonly encrust hydrophytes growing in alkaline, calcareous waters have been variously attributed to metabolic activities of bacteria, algae and the macrophytes.

The ash weights of the plants, calculated as a residue of the loss on ignition, ranged from 15.4% to 84.7% of the dry weight (Figure 17). Considerable intra-specific variation in ash weights was evident both among samples collected from the same impoundment and in samples collected from different impoundments. These intraspecific variations within single impoundments were most pronounced in the kettle lakes, where plant samples were collected from a wide range of water depths.

According to Westlake (1965), the ash weight usually ranges between 15 and 25% of the dry weight. However, it may exceed 50% in some calcareous material and may approach 70% in the Charophytes. The ash weights obtained for *Chara spp.* ranged from 31.7% to 84.7% in impoundment 19 and half of the samples had ash weights greater than 70% of the dry weight. The minimum ash weight value of 15.4% was recorded for a sample of *P. pectinatus* collected from impoundment 31; the maximum value recorded for this species was 48.5% in a sample obtained from impoundment #03. *P. strictifolius* collected from the latter impoundment had an ash weight of 20.0% compared to 36.0% obtained for the same species collected from impoundment #19, which had particularly hard water.

Concentrations of the micronutrients manganese and iron in plant tissues are summarized in Figures 18 and 19. In general, only slight intraspecific variations in the iron and manganese concentrations were observed for samples collected from a single impoundment but pronounced differences were observed for the same species of plants growing in different environments. However, since both the manganese and iron values varied widely with respect to % LOI, the extent of co-precipitation of these elements with marl was not clarified.

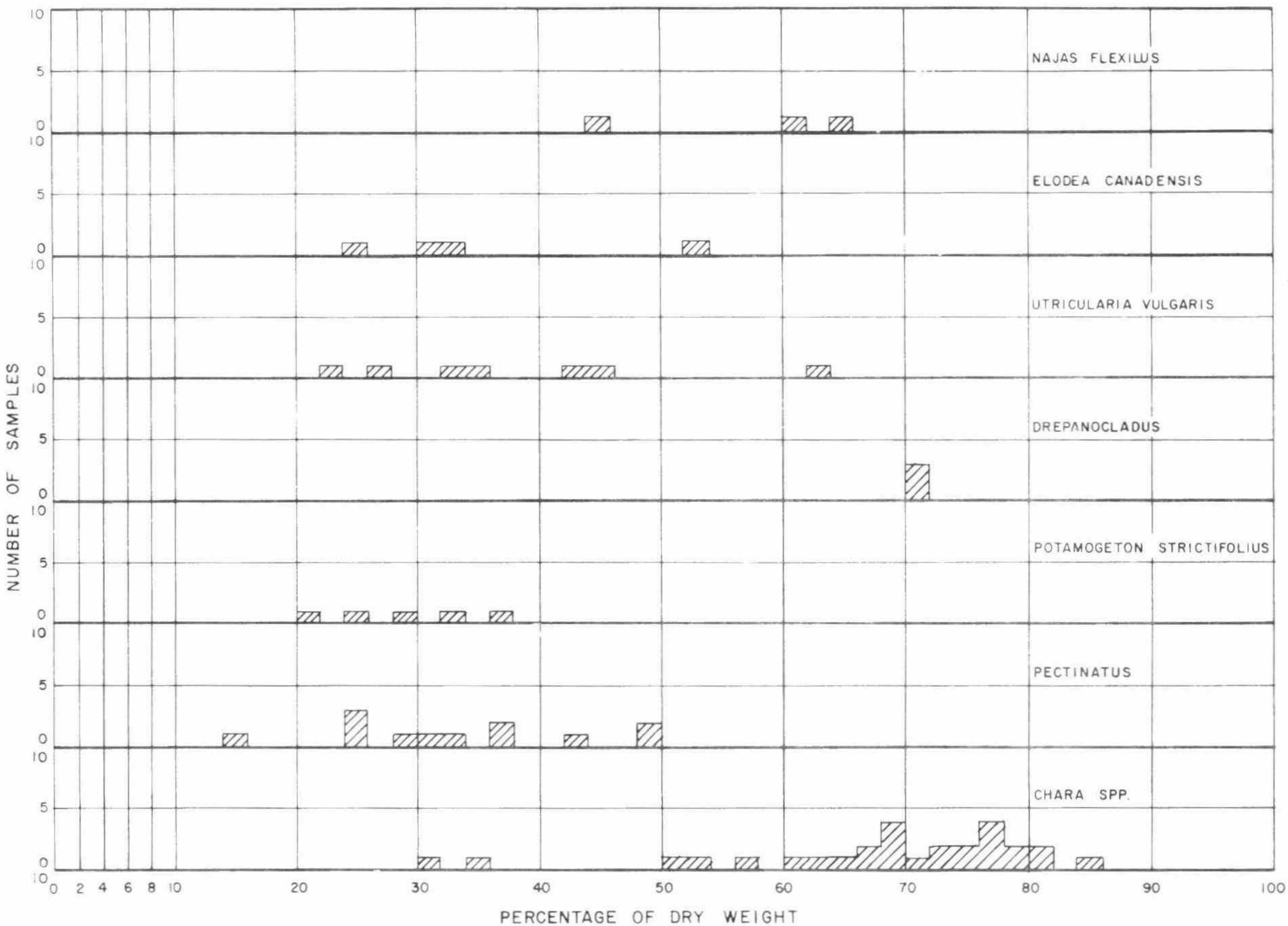

FIGURE 17. Ash content of plants expressed as a percentage of Dry Weight.

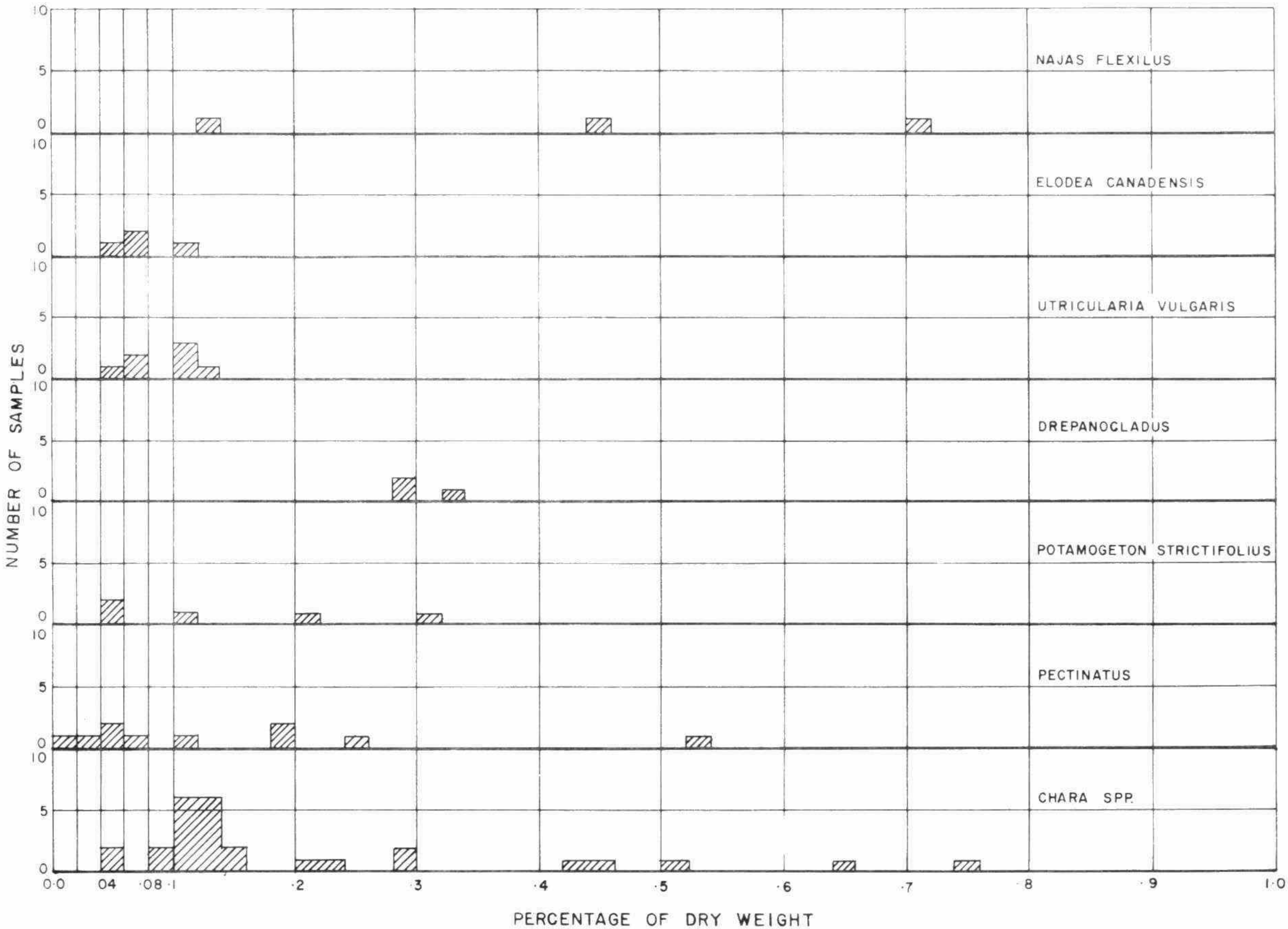

FIGURE 18. Manganese content of plants expressed as a percentage of Dry Weight.

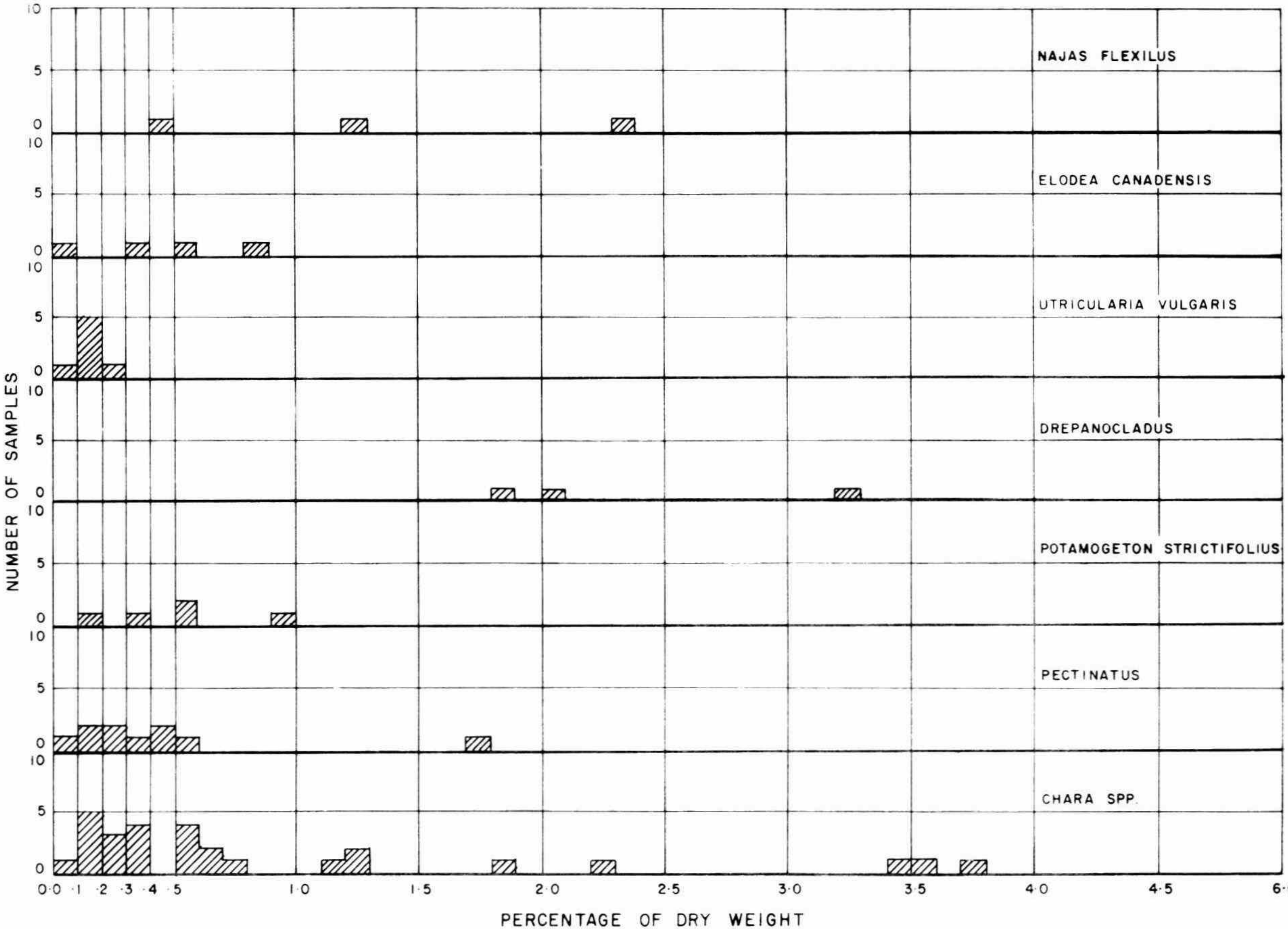

FIGURE 19. Iron content of plants expressed as a percentage of Dry Weight.

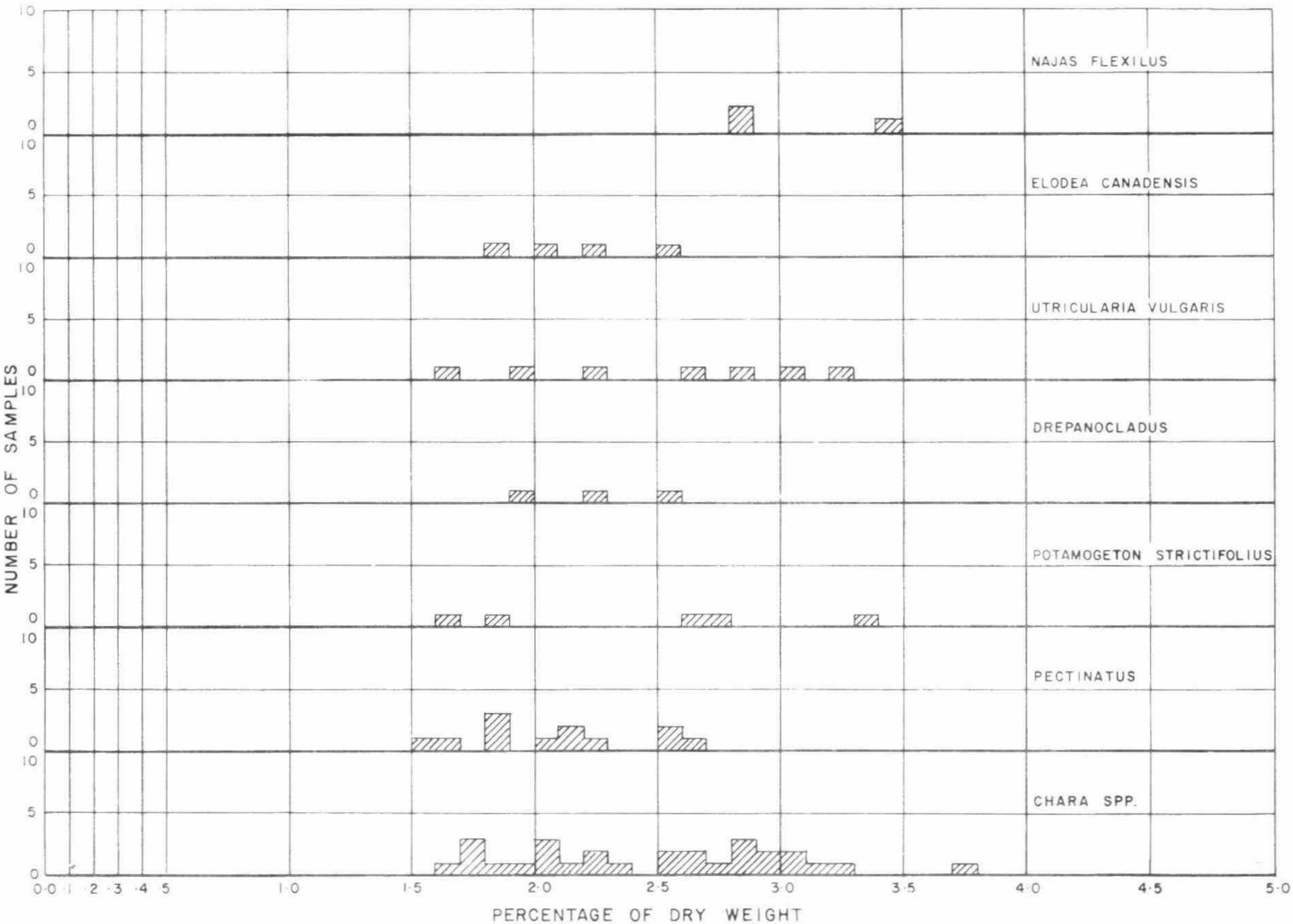

FIGURE 20. Nitrogen content of plants expressed as a percentage of Dry Weight.

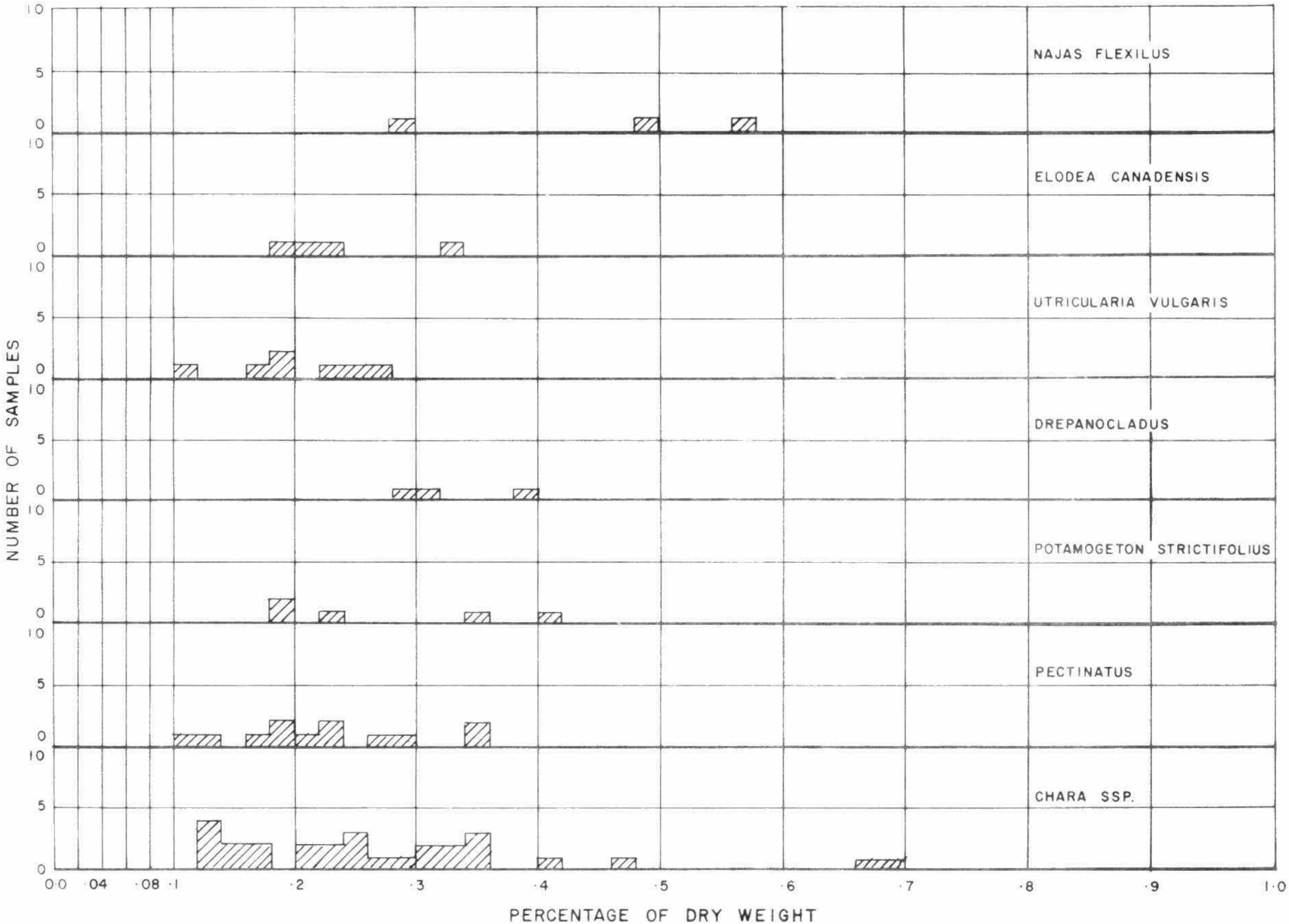

FIGURE 21. Phosphorus content of plants expressed as a percentage of Dry Weight.

Both the minimum (0.048%) and the maximum (3.705%) iron concentrations were obtained from samples of Chara spp. The lowest manganese concentration (0.017%) was recorded for P. pectinatus and the maximum value (0.756%) was again obtained from a sample of Chara spp.

Nitrogen and phosphorus concentrations in plant tissues are shown in Figures 20 and 21. Nitrogen concentrations ranged from 1.68% in P. pectinatus collected from impoundment #26 to a maximum of 3.7% in Chara spp., from impoundment #19. The minimum nitrogen value recorded for Chara spp., was 1.65%; the maximum for P. pectinatus was 2.60%. Phosphorus values ranged from 0.132% for P. pectinatus from impoundment #26 to a maximum of 0.69% in Chara spp., from impoundment #16.

Uptake and availability of nutrients

The concentrations of phosphorus, nitrogen, manganese and iron in plant tissues were compared to concentrations of these elements in surface and bottom waters and in the sediments.

Levels of total and soluble phosphorus in surface waters were found to be closely related to phosphorus concentrations in plant tissues (Figures 22 and 23). The co-efficients of correlation were + 0.660 and + 0.503 respectively and a t-test showed these co-efficients to be significant at $P = 0.05$ for 26 d.f. (Statistical Tables by F.J. Rohlf and R.R. Sokal., pg 225). The iron content of the plant tissues also showed a significant correlation with the concentrations in the surface waters (Figure 24) with a co-efficient of 0.694 for 23 d.f. There were no significant correlations between concentrations of nitrogen and manganese in the plant tissues and the surface waters.

When the concentrations of nutrients in plant tissues and the bottom waters were compared, no significant correlations were found. Similarly, no significant correlations were found between the nutrient levels in the plant tissues and the sediments.

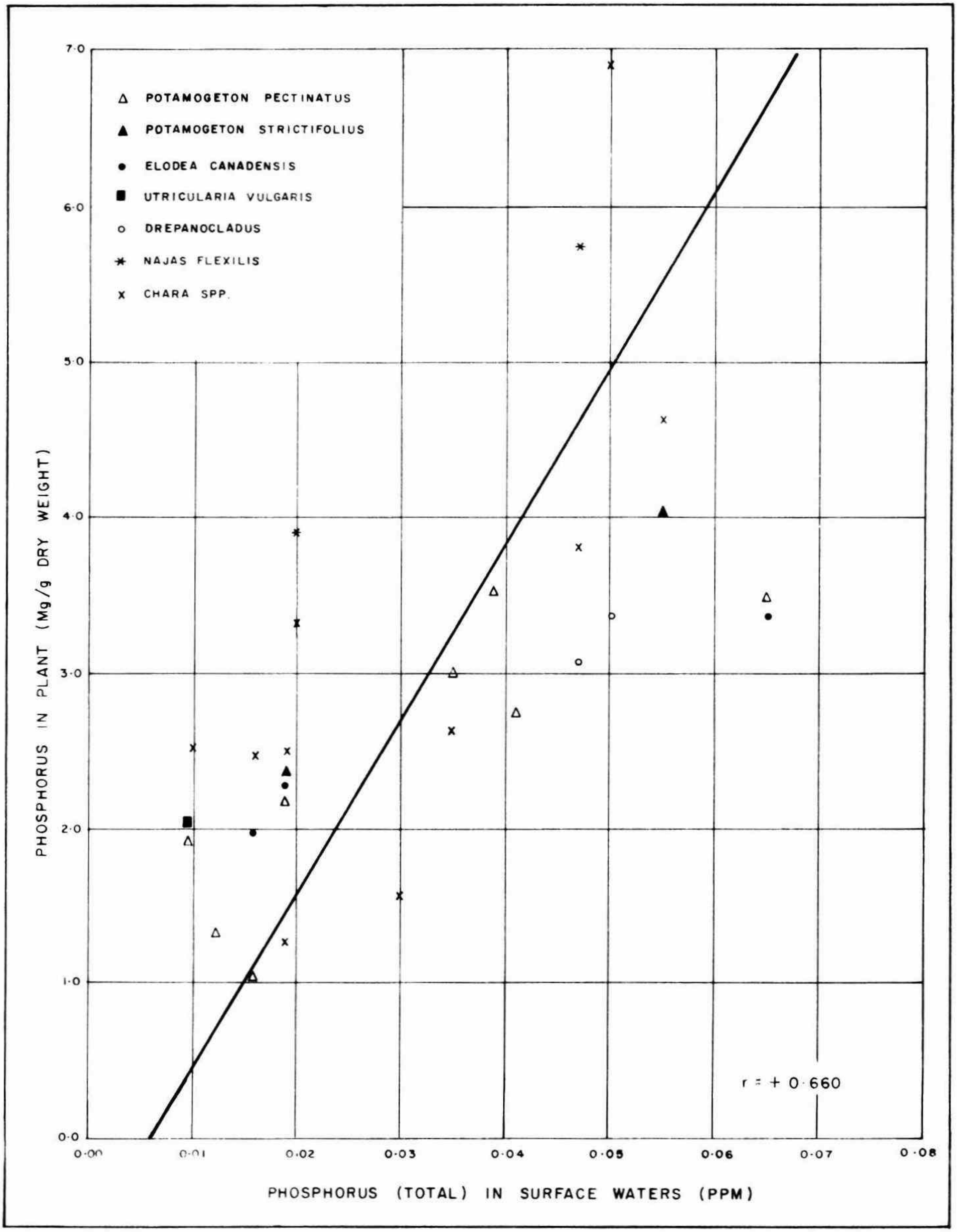

FIGURE 22. Correlation between phosphorus content of plant tissues and total phosphorus concentrations in surface waters.

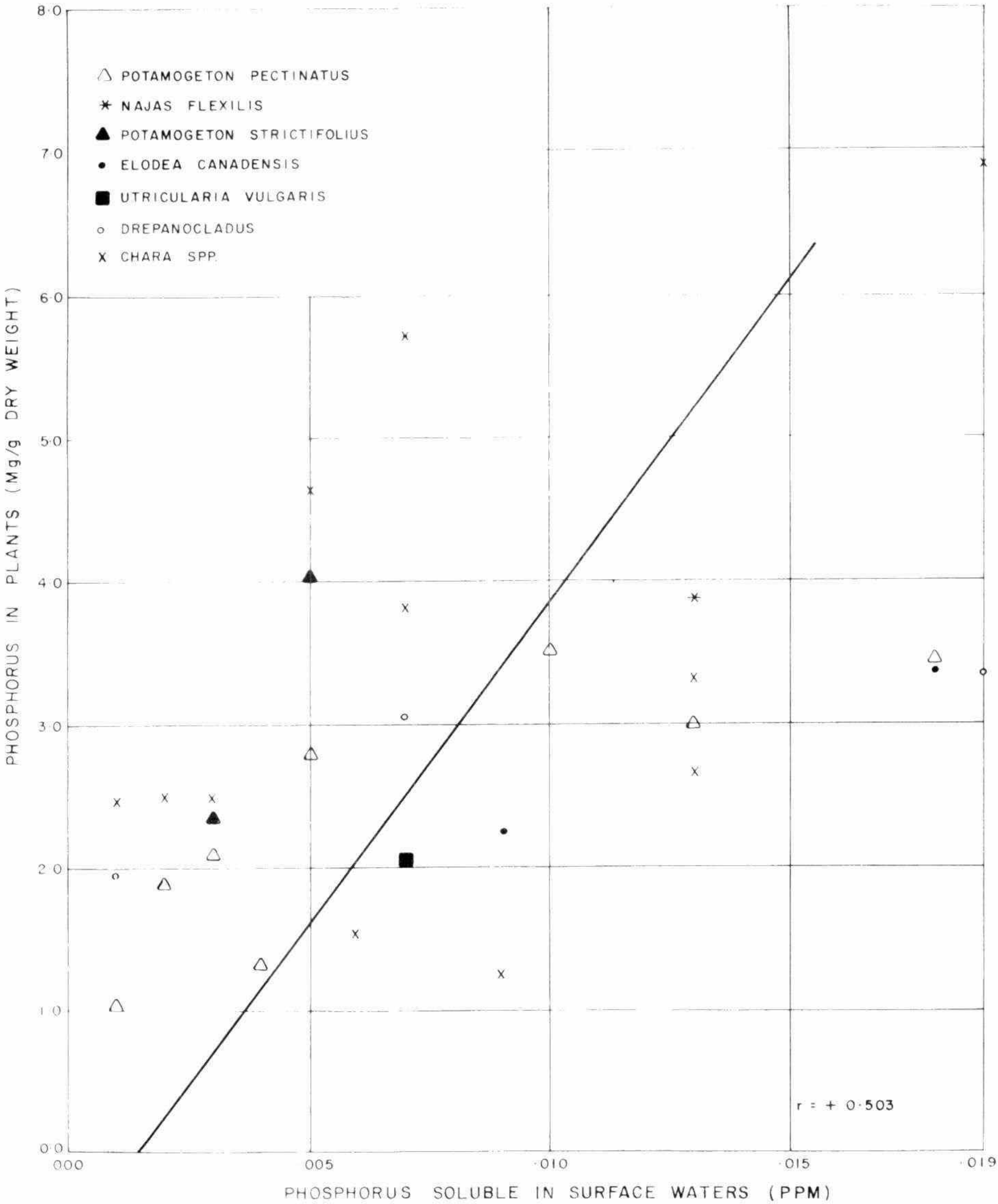

FIGURE 23. Correlation between phosphorus content of plant tissues and soluble phosphorus concentrations in surface waters.

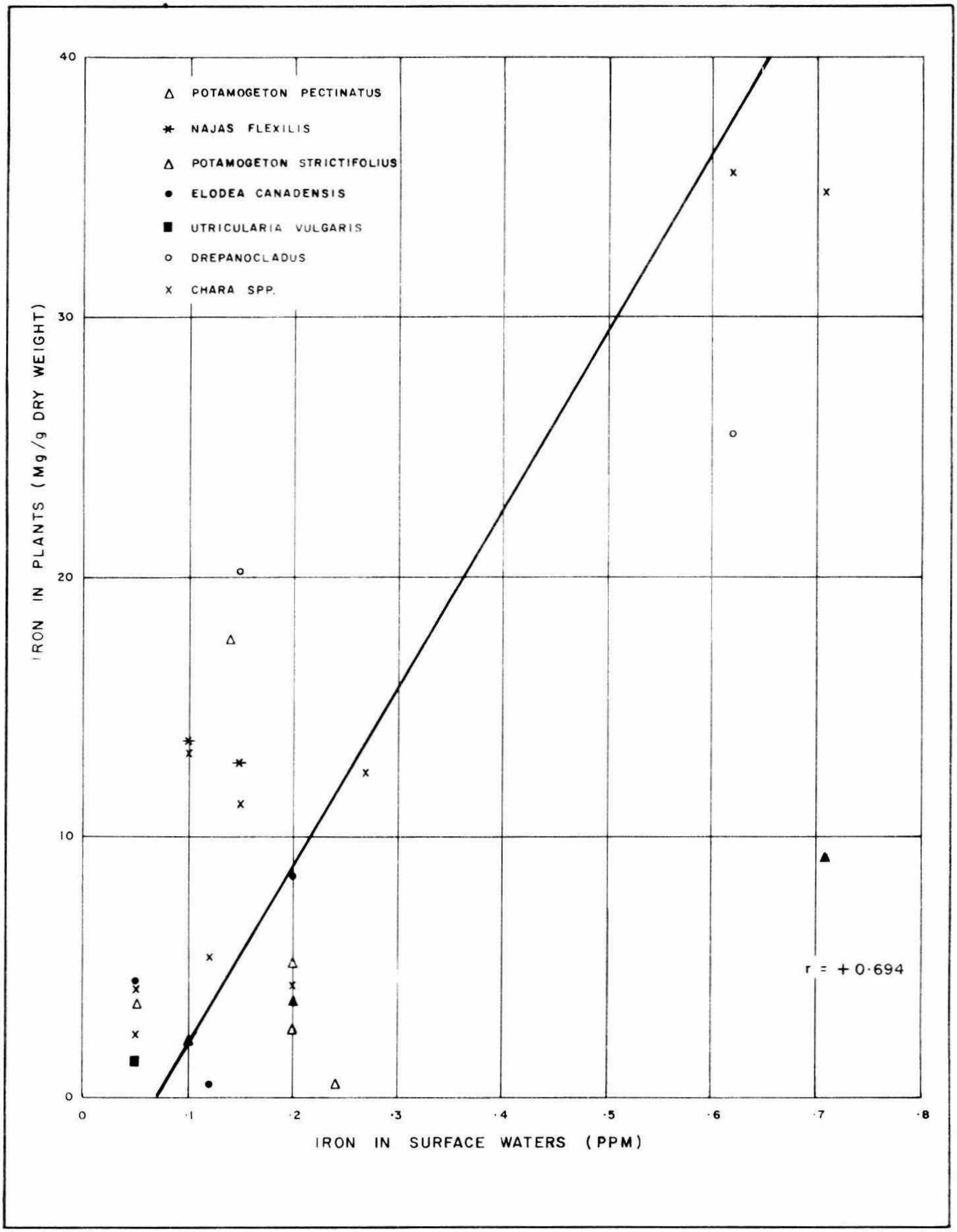

FIGURE 24 Correlation between iron content of plant tissues and iron concentrations of surface waters.

The plant communities: phytoplankton

Seasonal distribution and abundance

The quantitative and qualitative results for phytoplankton samples collected from selected impoundments during 1969 and 1970 are illustrated in Figures 25 to 29. Relative percentages of the four algal groups (blue-greens, greens, diatoms and flagellates) are indicated on bar graphs and the total phytoplankton counts, measured in a.s.u. per ml, are represented by line graphs.

In the trout and mill pounds (#31, 18, 28, 29, 32) the flagellate algae and the diatoms were co-dominant during the spring and fall of both 1969 and 1970. In most instances, the flagellate algae continued to dominate throughout the summer months. Prominent flagellates included Dinobryon, Haematococcus, Cryptomonas, Peridinium, Trachelomonas, Euglena and Chlamydomonas. The more common diatoms were: Synedra, Fragillaria, Cyclotella, Stephanodiscus, Nitzchia, Cymbella, Diatoma, Melosira, Tabellaria and Asterionella. Peak populations of green algae, comprised of Pediastrum, Scenedesmus, Schroederia, Spirogyra, Cosmarium and Chlorella were usually observed in late August or during September and October. Blue-green algae were notably prominent in only three of the ponds. Lyngbia was abundant in impoundment #28 and Anabaena, Chrococcus and Oscillatoria were prominent in impoundment #29 during June and July of both 1969 and 1970. The blue-green Gomphosphaeria temporarily dominated the algal population in pond #31 during August of 1969.

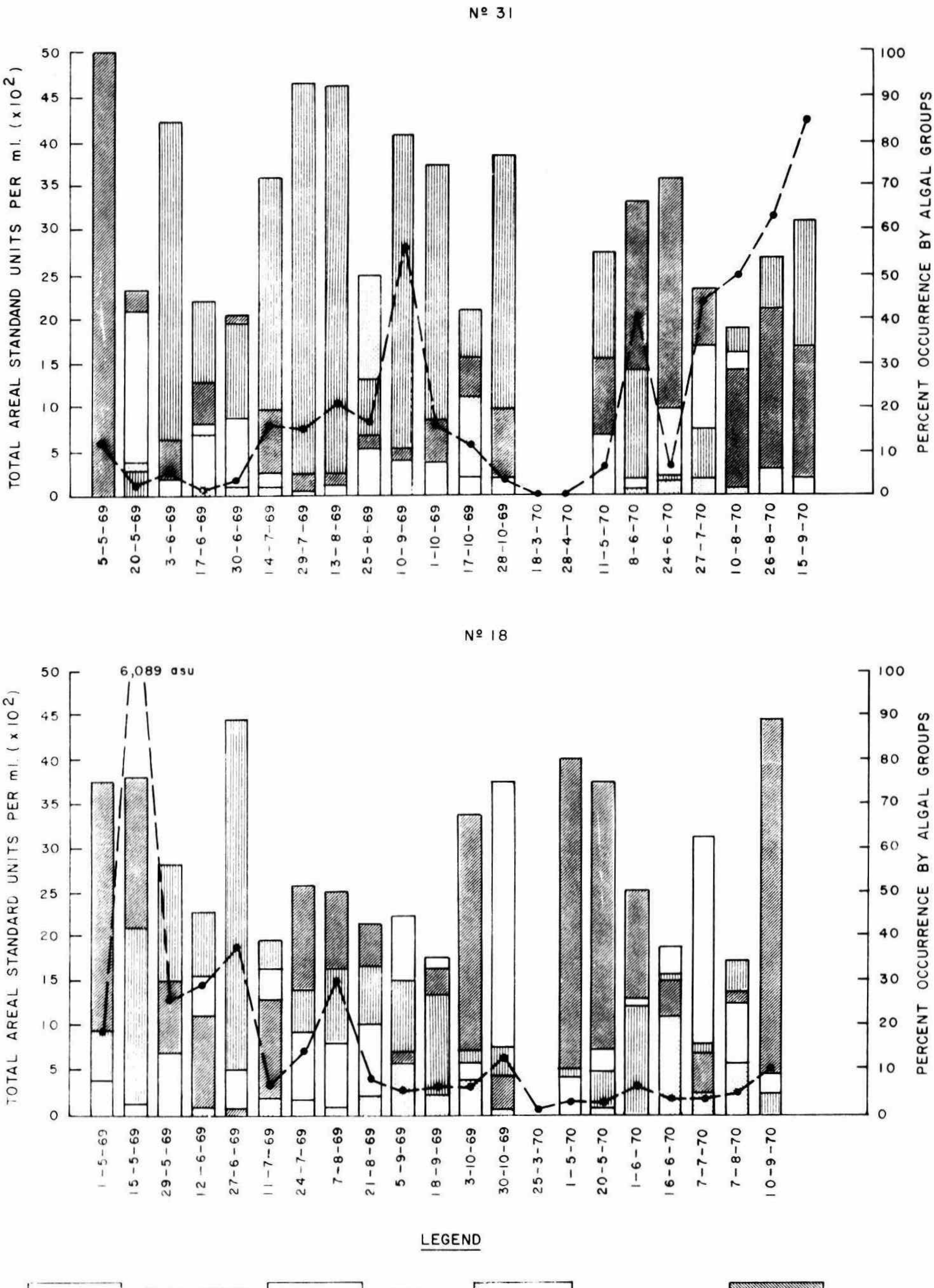

FIGURE 25. Standing stocks of phytoplankton in ponds 18 and 31.

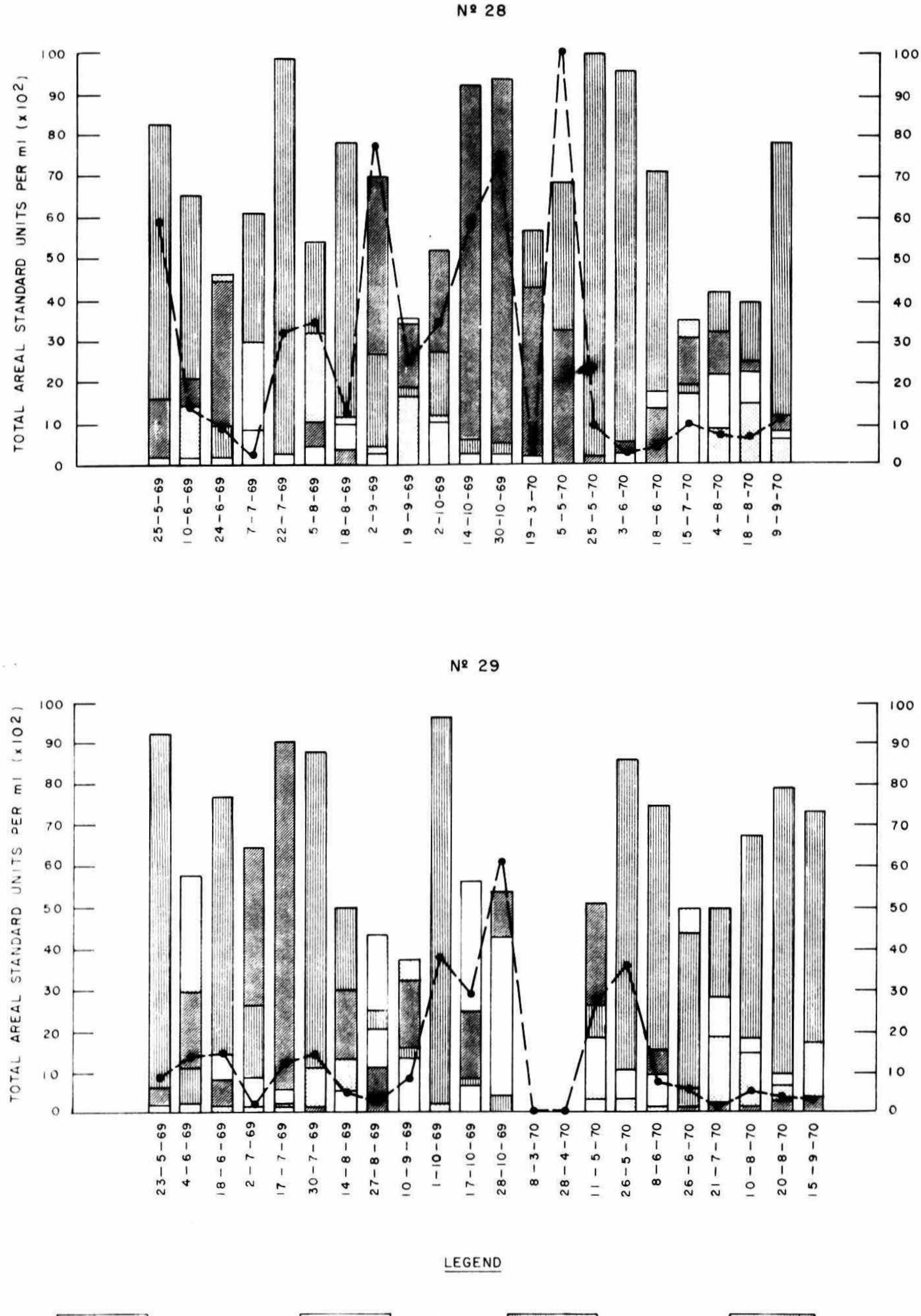

FIGURE 26. Standing stocks of phytoplankton in ponds 28 and 29.

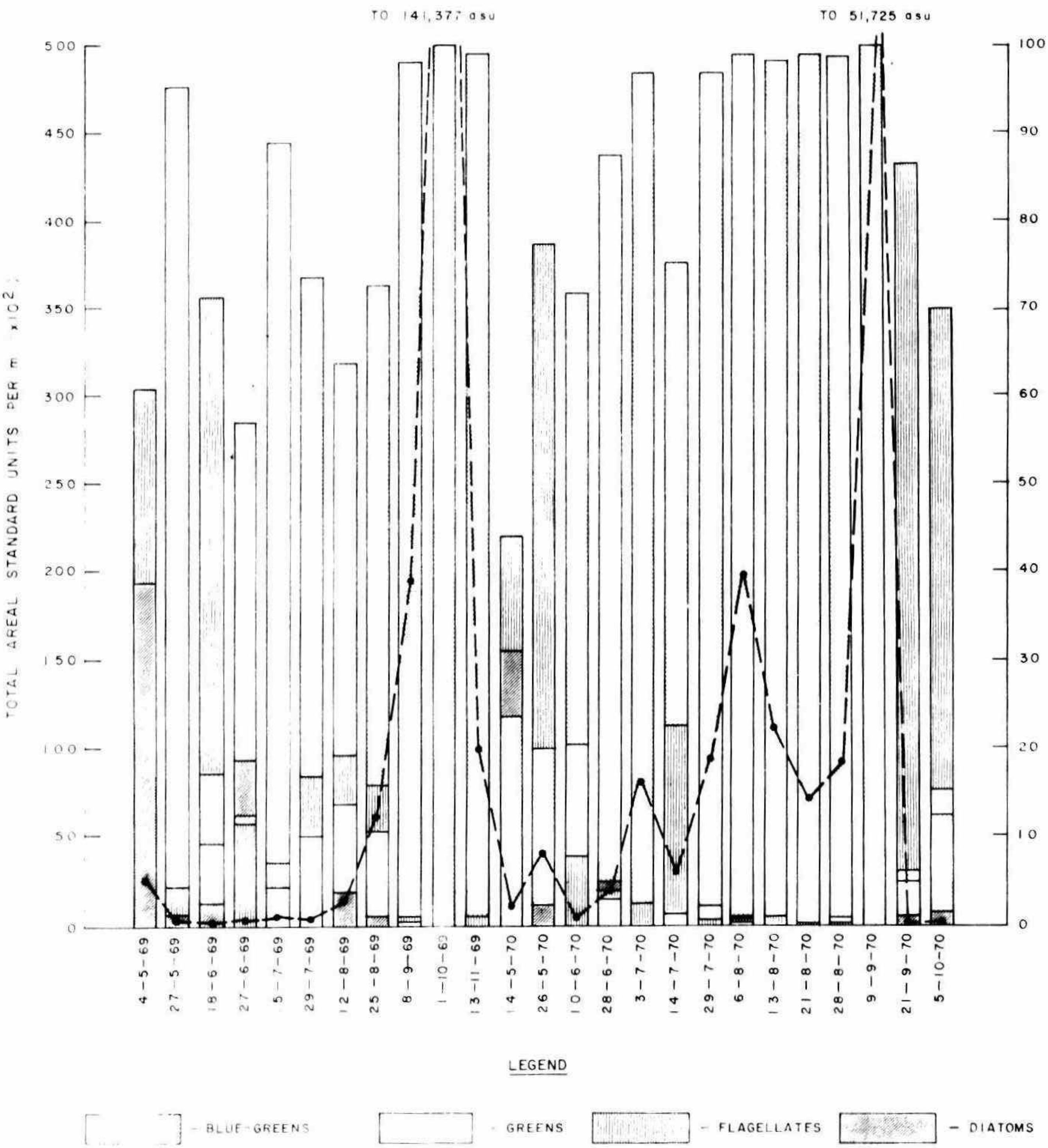

FIGURE 27. Standing stocks of phytoplankton in pond 03.

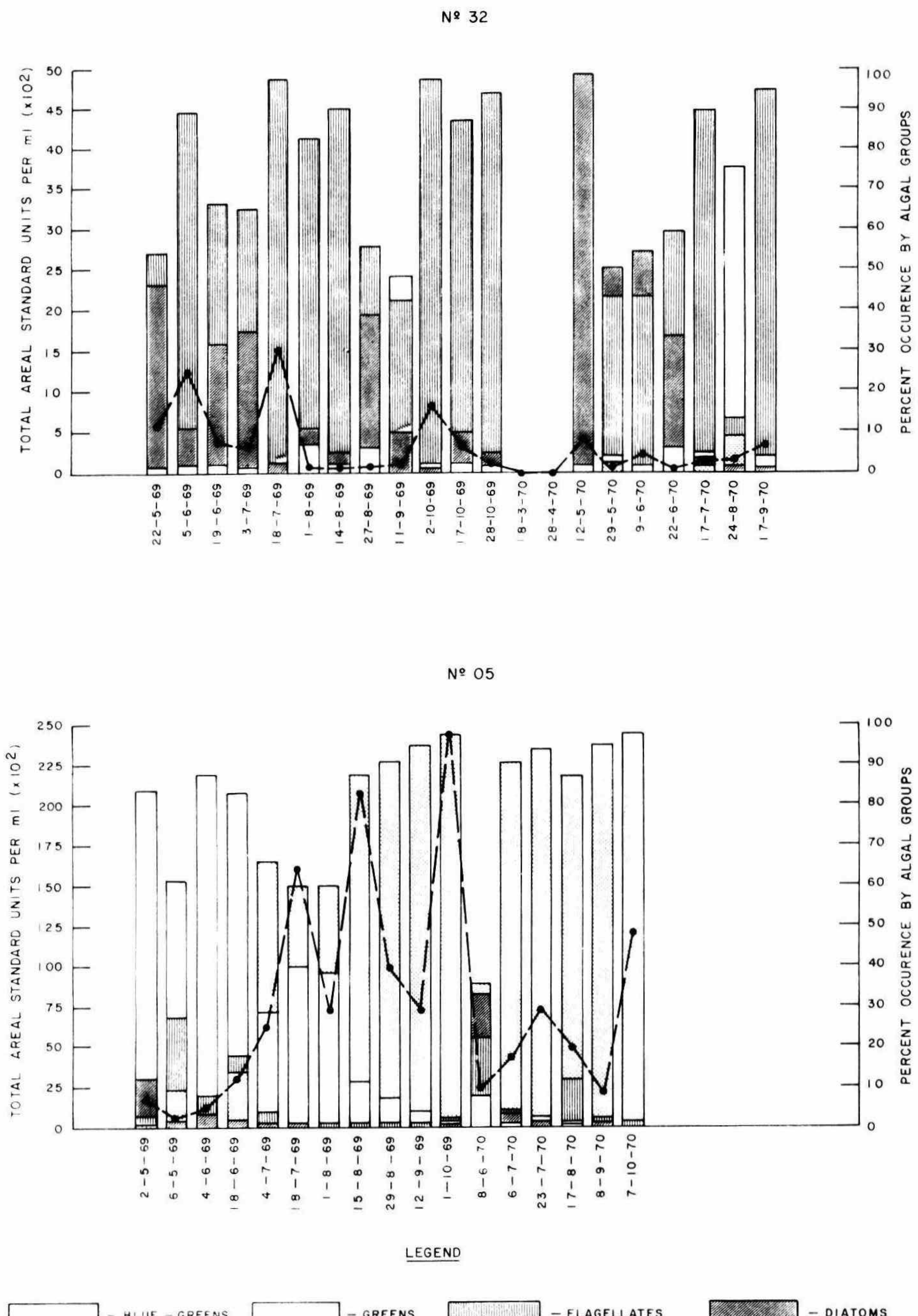

FIGURE 28. Standing stocks of phytoplankton in pond 32 and lake 05.

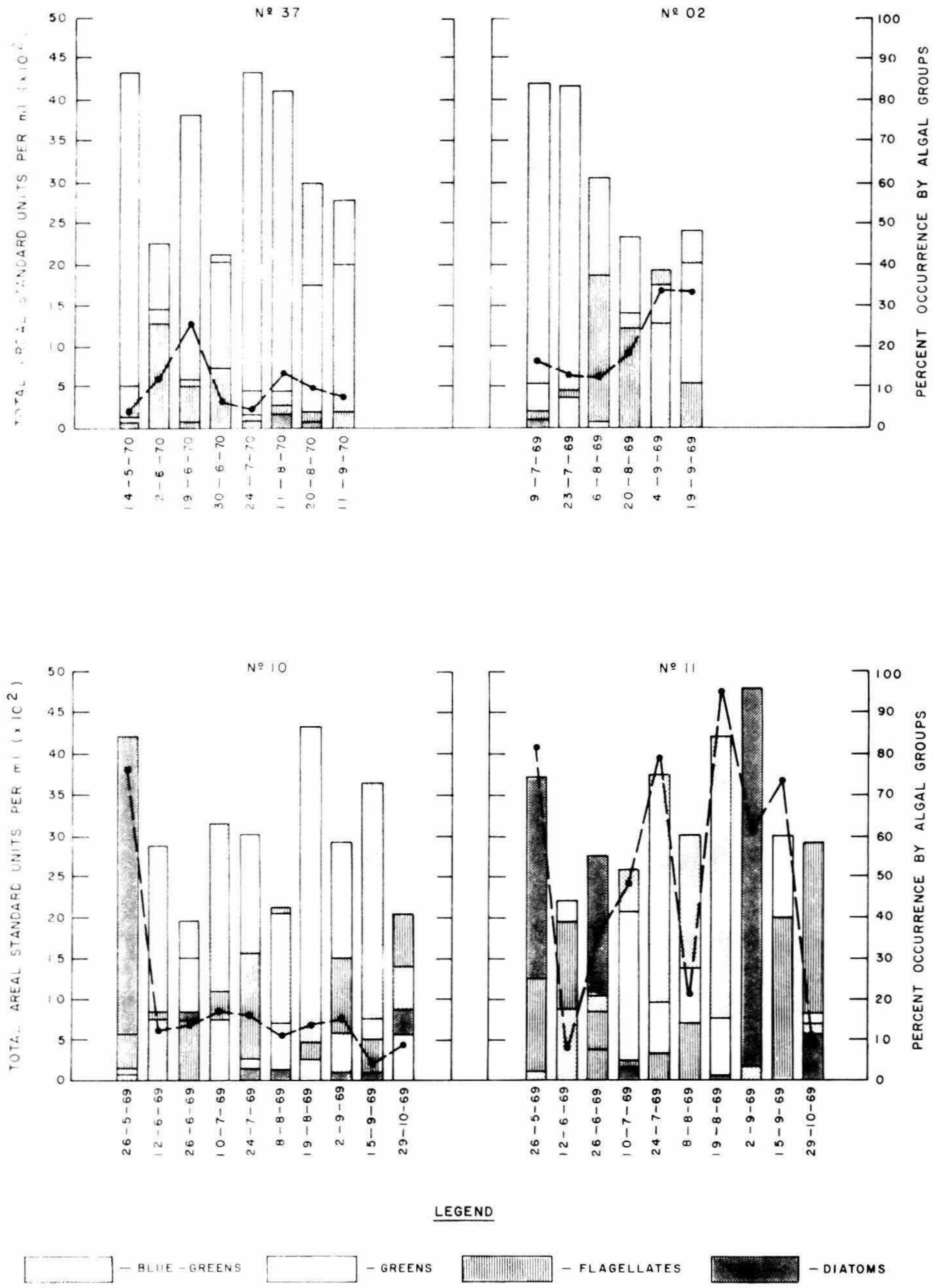

FIGURE 29. Standing stocks of phytoplankton in lakes 02, 10, 11 and 37.

Lowest a.s.u. values for the trout and mill ponds were recorded in pond #32, with counts generally well below 1,000 a.s.u. and a seasonal maxima of 1,525 a.s.u. Moderate counts were observed in ponds #31 and 18 with peak values reaching 4,258 and 6,089 a.s.u. respectively. The highest algal populations were attained in ponds #28 and 29 where approximately one half of the values exceeded 1,000 a.s.u. and seasonal maximas of 10,018 and 6,022 a.s.u. were obtained. With the exception of one pond (#31), which was dredged in the fall of 1969, substantially lower a.s.u. values were recorded during the 1970 sampling season.

In contrast to the above conditions, summer algal populations in impoundment #03 were entirely dominated by the blue-green alga Aphanizomenon. Bloom conditions prevailed both in 1969 and 1970 with peak values reaching 141,277 a.s.u. in October of 1969 and 61,725 a.s.u. in September of 1970.

Similarly, blue-green algae generally dominated the summer algal populations in the kettle lakes (#02, 05, 10 and 11). In lake 05 the blue-green alga Lyngbya persisted throughout the summer of 1969 and 1970 and reached peak values of 24,633 and 22,543 a.s.u. respectively. Also, the green alga Chlorella was particularly prominent during May and June of 1969. In the two basins (10 and 11) of another kettle lake, the blue-green algae Anacystis, Oscillatoria, Chroococcus, and Aphanothece dominated the summer algal populations. Other prominent algal forms included the green alga, Chlorella, the flagellates, Haemotococcus, Crytomonas, Dinobryon and Chlamydomonas and the diatoms Synedra and Fragillaria. While total a.s.u. values in basin #10 were generally low, the majority of the counts in basin #11 exceeded 3,000 a.s.u. The moderately low counts in kettle lake #02 were characterized by the blue-green alga Oscillatoria, and the greens, Crucigenia, Schroederia and Chlorella.

In the large shallow lake # 37, the scant algal populations were dominated by the green algae, Onychonema, Coelastrum, Cosmarium, Scenedesmus, Staurastrum and Kirchneriella during the spring and summer and by the blue-green alga Anacystis in late August.

Chlorophyll concentrations and Secchi disc readings

In a recent report on recreational lakes in Ontario, Brown (1972) suggests that there is a hyperbolic relation between the concentrations of chlorophyll-a and the Secchi disc readings. The chlorophyll concentrations are assumed to reflect the amounts of phytoplankton present and are plotted as ordinates. The corresponding Secchi disc readings are taken as measures of water transparency and plotted on the abscissae. Data for eutrophic lakes, which are characterized by high chlorophyll content and low transpraency, lie along the vertical limb of the hyperbola. Data for oligotrophic lakes, which have low chlorophyll content and high transparency, lie along the horizontal limb. Points for mesotrophic waters are distributed along the transitional portion of the curve. Plots of chlorophyll concentrations against Secchi disc readings for the present study are shown in Figure 30.

Most of the impoundments sampled can be classified as mesotrophic on the basis of the chlorophyll-Secchi disc relation. Exceptions are kettle lake # 02 which falls in the oligotrophic range, and ponds # 03, 16 and 17, which appear to be eutrophic.

In 1969, markedly different conditions were observed in the eastern and western lobes respectively of a single kettle lake (10 and 11). The comparatively high concentrations

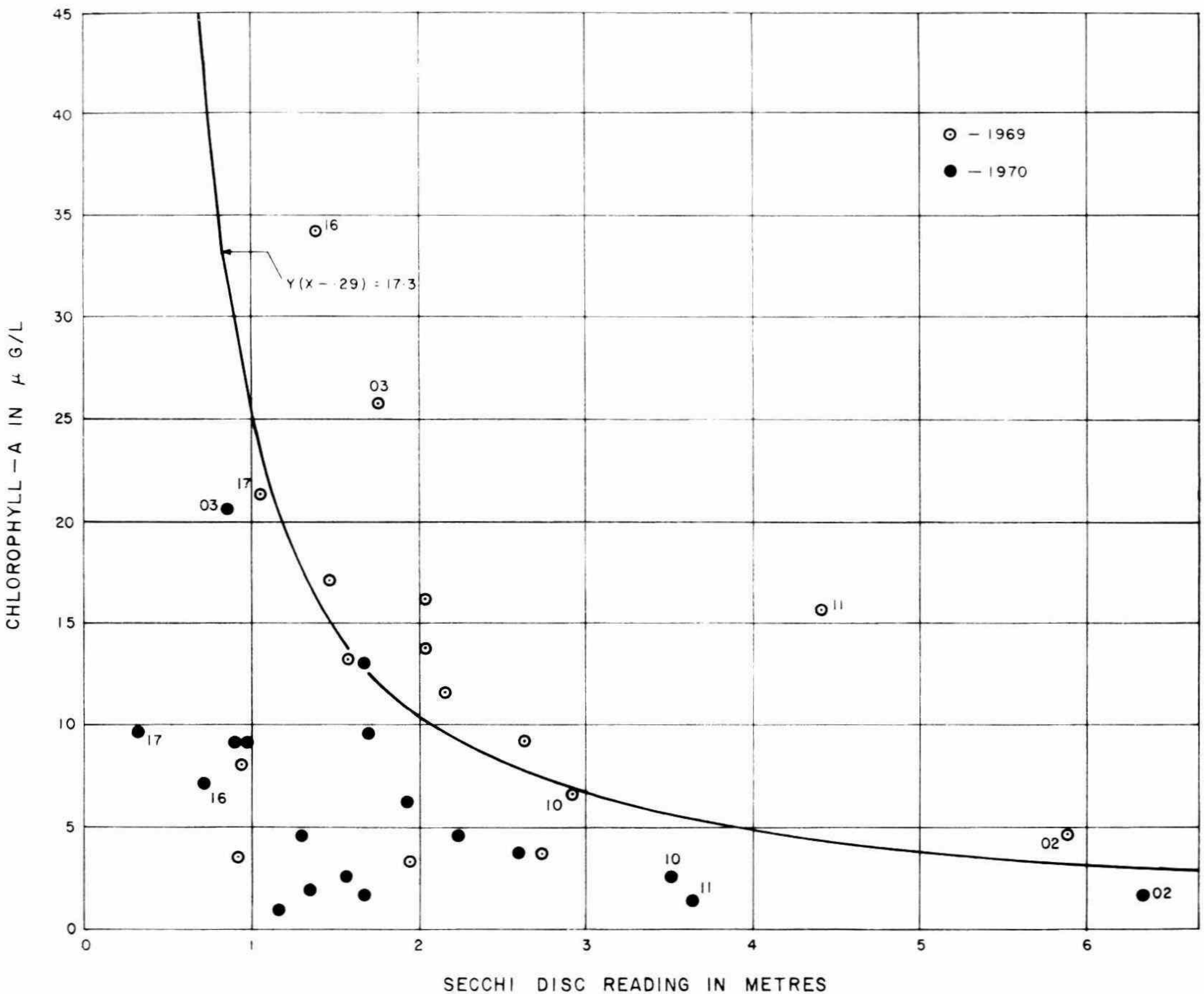

FIGURE 30. Relation between the mean chlorophyll a concentrations and Secchi disc readings, based on 1969 and 1970 samples.

of chlorophyll *a* in the western basin (11) suggest that phytoplankton was much more abundant there than in the eastern (10) basin. This is also borne out by the phytoplankton counts. At the same time the Secchi disc readings were consistently higher in the western lobe. The most likely explanation of this unusual combination of high chlorophyll concentrations and high transparency is that the phytoplankton in the western basin was concentrated in a layer just above the thermocline.

DISCUSSION

In general, the water chemistry of the impoundments reflect the fact that they are located in glacial over-burden, underlain by limestone and other sedimentary rocks. Calcium and magnesium are major components of both the soils on the watersheds and the waters. Consequently the waters are hard and neutral to slightly alkaline. Two borderline cases are the small kettle lakes #01 and 37, in which the waters are slightly acid (pH 6.7 - 6.9) at times. However, none of these impoundments are comparable in acidity to the waters in the Precambrian Shield.

Apart from this general similarity in hardness, pH and alkalinity, the water chemistry in these impoundments varies widely. In particular, mean concentrations of total dissolved solids range all the way from 90 to 519 ppm. The former value compares with that found in Lake Superior (Beeton 1965) and some of the oligotrophic lakes in the glacial Lake Agassiz basin but is higher than values found in the granitic area of the Precambrian Shield (Ryder 1964). The latter value is two to three times higher than the 180 to 200 ppm found in Lake Erie, the most highly eutrophied of the Great Lakes (Beeton 1965). On the basis of total dissolved solids most of the waters in this study could be classified as mesotrophic or eutrophic.

Among the factors responsible for the variation in total dissolved solids are differences in soil types and intensity of cultivation on the respective watersheds. The soils along the height of the Oak Ridges Moraine are generally light, sandy clays low in phosphorus and organic matter.

Furthermore, agriculture has been limited in these localities. Hence, the contribution to the total dissolved solids made by surface runoff from these watersheds would be relatively small. Most of the impoundments situated on headwaters in the Moraine lie within the lower half of the total dissolved solids range (90 to 300 ppm). In contrast, the soils on the till plains to the south of the Moraine are more productive and more intensely cultivated. Ponds located downstream in the till plains (notably 15, 16 and 17) are in the upper half of the range.

Another factor which has an important bearing on both the concentration and distribution of dissolved solids in impoundment waters is thermal stratification. In general, the sharper the thermal stratification is, the more pronounced the chemical stratification will be.

From the present study it would appear that wind mixing is very effective down to a depth of 3 or 4 m during the summer. Thermal stratification is weakly developed in all impoundments which are less that 4 to 5 m deep and in the deeper ones there is little change in temperature down to these depths. In contrast, the kettle lakes and flooded ponds which are 10 to 15 m deep and have high depth to area ratios, stratified strongly. Pond # 03, a long narrow body of 12.9 hectares area and about 8 m maximum depth appears to be an intermediate situation; it stratifies more strongly some years than others.

Besides affecting the thermal and chemical regimes of the impoundments, the depth has a direct bearing on the types of plants growing in them. Since green plants require light for photosynthesis, they are more or less confined to the zone into which sufficient sunlight can penetrate.

In the shallower impoundments (i.e. those up to 3 or 4 m in depth) the submergent macrophytes generally covered the entire bottom. In the kettle lakes the plants were confined to the littoral zone (3-4 m), although in the most transparent impoundment, # 02, Elodea canadensis was found thriving at a depth of 6 m. The only plants found in the deep basins of the kettle lakes were planktonic algae. Since the flooded sand pits are of recent origin, there is no significant growth of rooted macrophytes in them. However, a few plants are becoming established in pond # 34.

Although Chara spp. and Ceratophyllum demersum are present in the upper basin of pond 03, the general sparsity of macrophytes may be due to the fact that this pond is U-shaped in cross section, with little or no littoral zone and is subject to considerable wind action.

Among the chemical factors which influence the distribution of aquatic plants, hardness, alkalinity and pH are of major importance. From a study of their distribution, Moyle (1945) established the ranges of tolerance to alkalinity and pH for the more common species of aquatic macrophytes in Minnesota. He concluded that a total alkalinity of 40 ppm was the natural separation point between waters characterized by hard and soft water flora. The distribution of most of the plants collected in the present study conformed to the ranges established by Moyle, and were typical hard water species (Table 13). Two exceptions were P. epihydrus and P. obtusifolius which Moyle placed among the soft water flora but which occurred in the hard water kettle lakes # 20 and 26.

In study of the distribution of charophytes, Fosberg (1965) found that phosphorus was a major factor in determining their distribution. Luxuriant growths of charophytes were typical in oligotrophic lakes, characterized by high calcium levels and total phosphorus concentrations of 0.015 ppm.

TABLE 13: TOTAL ALKALINITY AND pH RANGES OF AQUATIC MACROPHYTES IN SOUTHERN ONTARIO IMPOUNDMENTS

Species	No. of Impound-ments	Alkalinity range	pH range
Chara spp.	17	60 - 223	6.9 - 8.4
Potamogeton pectinatus L.	13	101 - 223	7.1 - 8.4
Potamogeton foliosus Raf.	7	148 - 223	7.1 - 8.2
Potamogeton nodosus Poir.	1	172	8.4
Potamogeton strictafolius Benn.	3	123 - 172	8.2
Potamogeton natans L.	3	141 - 164	7.8 - 8.3
Potamogeton amplifolius Tuckerm.	2	60 - 65	6.9 - 7.0
Potamogeton epihydrus Raf.	1	202	8.3
Potamogeton obtusifolius Mert & Koch.	1	125	8.1
Potamogeton zosteriformis Fern	2	125 - 202	8.1 - 8.3
Potamogeton crispus L.	1	204	7.8
Najas flexilis (Willd.)	6	123 - 223	7.1 - 8.2
Elodea canadensis (Michx.)	4	101 - 176	7.7 - 8.4
Utricularia vulgaris L.	4	60 - 202	6.9 - 8.4
Ceratophyllum demersum L.	2	172 - 204	7.8 - 8.4
Ceratophyllum echinatum Gray.	3	123 - 157	8.1 - 8.4
Myriophyllum exalbescens Fernald	2	166 - 176	7.7
Polygonum natans Eat.	4	123 - 202	7.8 - 8.3
Polygonum coccineum Muhl.	1	204	7.8
Drepanocladus	3	158 - 223	7.1 - 8.2
Lemna minor L.	4	60 - 204	6.9 - 7.8

Charophytes also flourished in moderately eutrophic lakes with total phosphorus concentrations around 0.020 ppm but were in direct competition with the phanerograms.

In the present study, the charophytes were prolific in 10 impoundments, where phosphorus concentrations ranged from 0.010 to 0.035 ppm. However, in lake #37, the seasonal average calcium concentration of 20 ppm and conductivity of 82 micromhos/cm^2 were well below the values outlined by Fosberg. Chara spp., also flourished in ponds #16 and 19 at relatively high phosphorus concentrations of 0.050 and 0.055 ppm respectively. Both these ponds were also characterized by excessively high calcium levels (85 and 82 ppm) and very high conductivities (519 and 549 micromhos/cm^2).

Numerous authors have reported that the uptake of macronutrients by aquatic plants is greater with increasing environmental levels of these elements. Fish and Will (1966) found concentrations of 2.8% nitrogen and 0.34% phosphorus in Elodea candensis growing in the oligotrophic Lake Okataina compared to concentrations of 4.48% N and 0.75%P in the same species from the highly enriched Lake Rotorua, New Zealand. Caines (1965 reported significant increases in phosphorus concentrations of Myriophyllum alterniflorum and Potamogeton praelongus following addition of calcium superphosphate to their environment.

The concentrations of certain nutrient elements in the tissues of plants collected from Southern Ontario impoundments were found to be closely related to the concentrations of these elements in the surface waters. Significant correlations were found in the case of iron, total and soluble phosphorus (Figures 22, 23 and 24). However, there was no significant correlation between concentrations of nitrogen and manganese in the plant tissues and in the surface waters.

Although the concentrations of nutrients in the plant tissues and in the bottom waters were not significant, the lack of correlation was not entirely unexpected since a major portion of the bottom water samples were collected from depths below the euphotic zone.

The role of sediments in the nutrition of aquatic plants was investigated by Misra (1938), Pearsall (1920), Bristow and Whitcombe (1971) and others but to date the proportion of mineral uptake through the root system has not been determined. Fosberg (1960) compared the total weight of phosphorus in the aquatic vegetation to the phosphorus content of the waters in Lake Osby, Sweden. Since the plants contained substantially more phosphorus than was available from the water, he concluded that a major portion of this element originated from the sediment.

In the present study, no significant correlations were found between the concentrations of phosphorus, nitrogen, iron and manganese in the plant tissues and the concentrations in the sediments. However, large variations in phosphorus concentrations were found among single species collected from varied environments but similar concentrations were found in different species collected from the same impoundments. The lack of correlation between nutrient concentrations in the plant tissues and the substrate could possibly be attributed to the differential depth of penetration of the roots of the various species of plants. Since only the top centimeter of soil was retained for analysis, the samples would not in many instances be truly representative of the sediment from which the plants would obtain the nutrients.

Gerloff and Kromblantz (1966) considered the concentration of an element in the plant tissue as a reliable indicator of the supply of that element in the environment and used the plant tissue analysis technique as an index of availability of nitrogen and phosphorus in natural waters.

Based on laboratory experiments with numerous species of angiosperms, the authors established critical tissue concentrations of 1.3% nitrogen and 0.13% phosphorus. Plant tissue concentrations below these critical levels would indicate that plant growth is limited by the supply of that element. Tissue concentrations above the critical levels have no relation to yield but represent "luxury uptake".

In the present study concentrations of nitrogen and phosphorus in tissues of the angiosperms collected from 12 different impoundments were well above the critical levels established by Gerloff and Kromblantz, indicating that growth of the plants was not limited by the supply of these elements.

When the quantities of mineral contained in aquatic plants are compared to typical water analyses, it is evident that the uptake represents a large portion of the available nutrients in the environment. While nutrients removed from the water by phytoplankton are recycled rapidly, the macrophytes effectively remove large quantities of nutrients from circulation for extended periods of time. For instance, in the highly productive impoundment #32, a net quantity of 89 kg/ha of nitrogen and 7 kg/ha of phosphorus were contained in the plant biomass at the time of sampling.

The competition between macrophytes and phytoplankton for available nutrients has been documented (Hasler and Jones, 1949; Cottom and Nicols 1970; Goulder 1969). Recent evidence indicates that macrophytes absorb nutrients early in the growing season at a proportionally greater rate than later in the season (Boyd 1967; Caines 1965; Wile, unpublished data). This pattern of nutrient uptake gives the macrophytes

a competative advantage over phytoplankton, particularily in relatively infertile waters. This appeared to be the case in pond # 32 and lake # 37 which were characterized by a paucity of phytoplankton but which supported large standing crops of macrophytes. Although moderately high seasonal maxima for phytoplankton were recorded in the remaining ponds, these values were generally observed only in spring prior to development of the macrophytes or in fall following the decline of the macrophytes. In contrast, in kettle lakes # 05 and 10 and pond # 03 where growths of mcarophytes were sparse or restricted to comparatively small littoral zones, the standing crops of phytoplankton were heavy during the summer.

Blue-green algae were major components of the phytoplankton of the kettle lakes and pond 03, in which the hypolimnal waters became anaerobic. They were much less prominent in the shallower, well aerated ponds. Sirenko et al (1969) have suggested that the development of blooms of blue green algae in certain Russian reservoirs was correlated with anaerobic conditions.

MANAGEMENT IMPLICATIONS

From the present study, it is evident that submersed auqatic plants remove vast quantities of nutrients from their environment. For instance in the highly productive impoundment # 32, a net quantity of 89 kg/ha of nitrogen and 7 kg/ha of phosphorus were contained in the plant biomass at the time of sampling. Based on the annual per capita contribution of 4.0 Kg N and and 1.4 Kg P to treated sewage (Mackenthum, 1967), the nutrients tied up in the plant biomass in one hectare of the above pond correspond to the nitrogen contribution of 22 persons and phosphorus contribution of 5 persons per year.

Boyd (1970) has suggested that this capacity of aquatic plants to tie-up nutrients should be exploited as a means of stripping nutrients from effluents and natural waters.

In light of the above evidence, serious consideration should be given to mechanical harvesting as a method for controlling excessive plant growth. Although for reasons of cost and expediency, aquatic plants are usually erradicated by chemical methods, the resulting decomposition of the plant remains may place severe stress on the oxygen resources. Furthermore, decomposition returns nutrients to the environment where they are utilized by phytoplankton or other species of macrophytes.

On the other hand, mechanical harvesting, in addition to placing less stress on the oxygen regime, also represents a potential method of nutrient removal. Since nutrient concentrations in the plant tissues vary in the relation to their environment, proportionately larger quantities of nutrients would be removed from more fertile waters.

ACKNOWLEDGMENT

We wish to thank the owners for permission to work on the impoundments and for other courtesies. The services of The Laboratory Branch, Ministry of the Environment, are also appreciated. We are especially indebted to Dr. T. Brydges for his assistance during the course of this study and to Dr. J. Leach, Mr. C. Schenk and Mr. M. Michalski for editing the manuscript.

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APPENDIX 1

Aquatic Plant Analysis

T.G. Brydes and J.J. Evans

INTRODUCTION

Most routine analytical methods used by the Ministry laboratories require the sample to be in solution. Solid materials, such as dried plants, require considerable preparation prior to final analysis and the procedures used for the plant samples are described in this Appendix. The results are discussed in light of interference by the marl content.

Sample Preparation

Whole plants were sorted according to species and location and were air dried to constant weight before delivery to the laboratory. The samples ranged from a few milligrams to several hundred grams. Drying at 105°C resulted in a further weight loss of less than 1% so this was not done on a routine basis.

Various grinding and cutting methods were tried but the most effective was grinding with a mortar and pestle along with a convenient amount of dry ice. The dry ice serves as a grinding compound and the low temperature makes the plant material more brittle. Entire plants including large stocks were readily reduced to a fine powder. The powdered mixture was allowed to warm to room temperature in a 4 oz. glass jar with the top loosely put on. The escaping carbon dioxide kept water vapor out of the bottle and prevented condensation in the sample. Approximately twenty-five gram aliquots were ground up when available. Complete plants were selected when possible in order to arrive at an overall average concentration.

Most samples contained percentage quantities of marl (calcium and magnesium carbonates) deposited during growth. It was such an integral part of the plants that separation by dilute acid washing or screening were not successful. No attempts were made to acid wash the powdered sample because of the danger of removing plant constituents from the broken surfaces.

Analytical Methods

Samples were analyzed in duplicate for loss on ignition at 600^{o}C, total nitrogen and phosphorus, iron, manganese, calcium and magnesium. Shortage of material in some cases necessitated single analyses of a reduced number of tests.

Loss on Ignition

One half to one gram aliquots were heated to 600^{o}C for one hour in tared porcelain dishes and the weight loss was recorded. Preliminary testing showed that there was no additional weight loss on heating for an extra two hours, indicating complete combustion and no slow decomposition of carbonates.

The weight loss was reproducible to within 2% and duplicates outside of this range were repeated. The reported results were the arithmetic mean of the duplicates expressed as the percentage of the dry weight lost during ignition.

Total Nitrogen and Phosphorus

Twenty milligram aliquots were digested with 3 ml of 50% sulphuric acid and sufficient potassium persulphate to give a clear solution, usually less than 4 grams. The digest was heated to fuming to destroy excess persulphate then cooled and diluted to 100 ml after adjusting the pH to 3.5. Total nitrogen and phosphorus determinations were made simultaneously on an Auto Analyzer using the alkaline phenol

hypochlorite and phosphomolybdate blue methods, respectively.

Duplicates were accepted and averaged up to a maximum difference of 10%. Results outside of this range were rejected and the digestions were repeated. The results were conveniently expressed in milligrams per gram of dry sample.

Iron, Manganese, Calcium and Magnesium

Approximately 100 mgm aliquots were digested with 3 ml of 50% sulphuric acid and enough nitric acid to give a clear solution and boiled to near dryness to destroy excess nitric acid. The residue was dissolved in 150 ml of water and the iron content determined by the o-phenanthrolene method. Manganese, calcium and magnesium analyses were carried out by atomic absorption spectroscopy. Lanthanum solution was added for the calcium and magnesium tests to mask the effect of the sulphate ions.

RESULTS

Since it was not possible to satisfactorily remove the marl before analysis, the results were not in terms of the weight of real plant material. The actual elemental concentrations in the plants can be calculated from the overall concentration if it is assumed that all of the loss on ignition is due to the plant material and that the calcium and magnesium in the plant material is very low relative to the marl content. Figure 1 is a graph of the sum of calcium and magnesium expressed as carbonates versus the percentage loss on ignition. The line is a least squares fit and indicates that for pure plant material (zero marl)

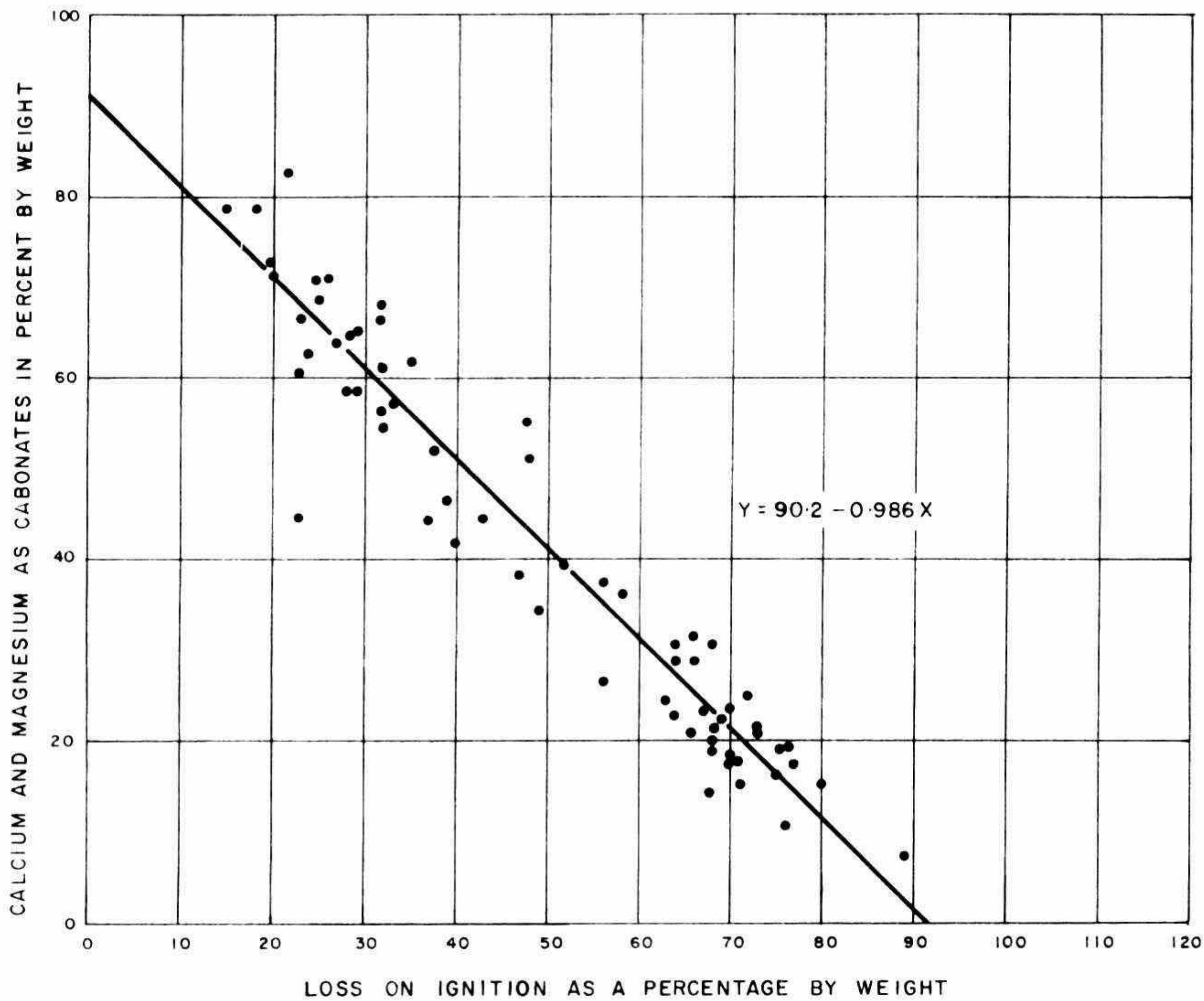

FIGURE 1. Calcium and magnesium as carbonates in percent of the dry weight versus the loss on ignition at 600°C for samples of aquatic plant material.

the loss on ignition would by 91.5%. This was shown to be the case for ordinary lawn grass which of course contains no marl. Therefore, the amount of plant material in a given sample is expressed by the equation,

plant material (percent) = loss on ignition (percent) x 100/91.5....(1)

The actual concentrations in the plants may be calculated by equation 2, thus compensating for the marl content,

C = Co x 91.5 (loss on ignition in percent)....(2)

Where C = concentration per unit weight of plant material,

Co = concentration per unit weight of plant material-marl mixture.

A single result fell well below the line in Figure 1 and replicates indicated correct data. The carbonate content was determined by titration with standardized hydrochloric acid with heating and stirring and the result confirmed the calcium and magnesium analyses.

The loss on ignition of the residue was still only 33% while for zero marl content the expected result was 91.5%. Therefore, it was concluded that in this single case there was inert material incorporated into the marl. Similar titrations on two samples falling close to the line in Figure 1 gave good agreement between the carbonate and the calcium and magnesium content and the subsequent residue loss on ignitions rose to 88% and 91.5%.

It is possible that other elements, particularly phosphorus and iron could co-precipitate with the marl, thus making these results incorrect in terms of plant material.

The nitrogen and phosphorus results are plotted against the loss on ignition in Figures 2 and 3 respectively. Low loss on ignition values correspond to high marl content.

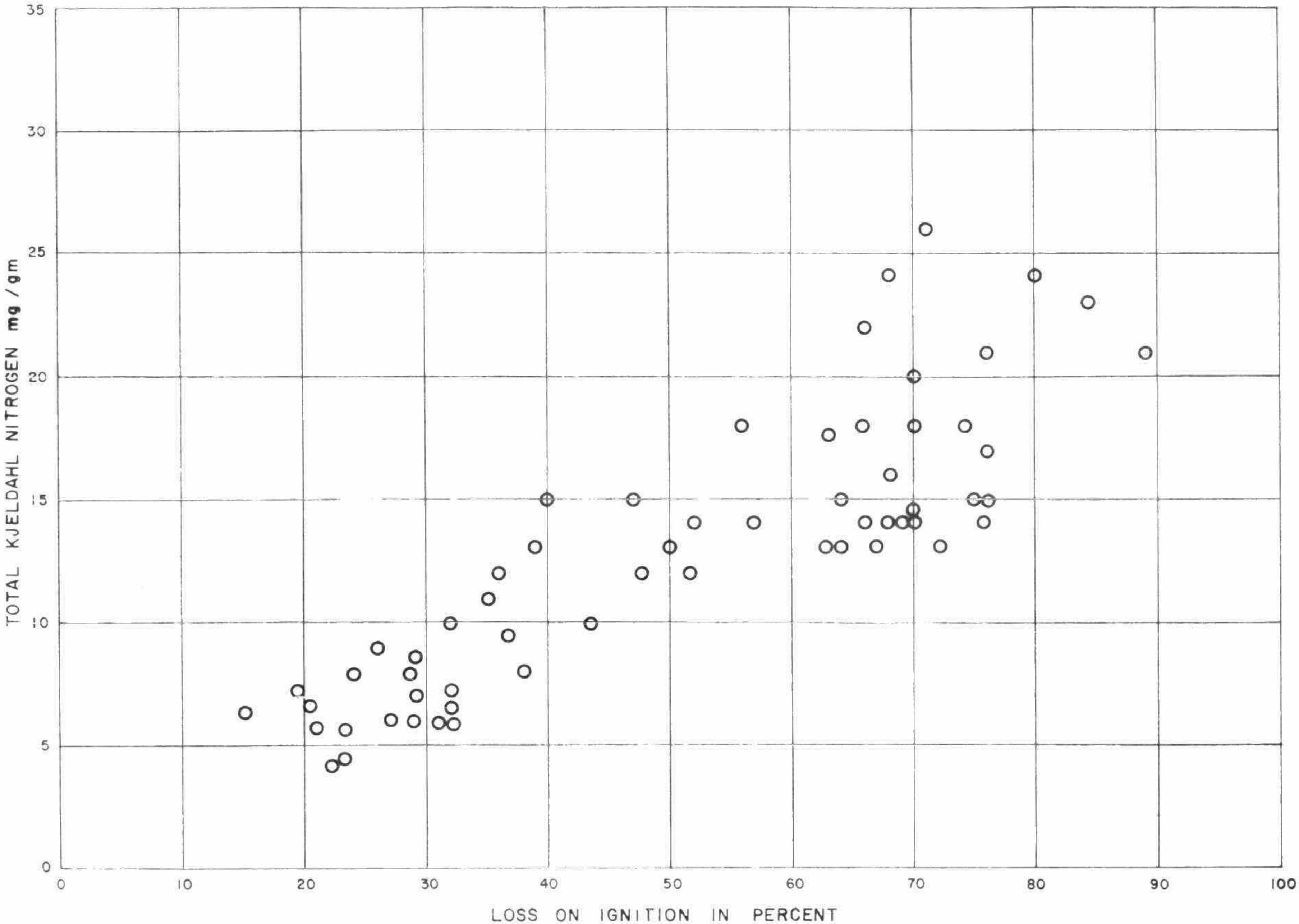

FIGURE 2. Total Kjeldahl nitrogen in mg/gm plant-marl mixture versus loss on ignition in percent.

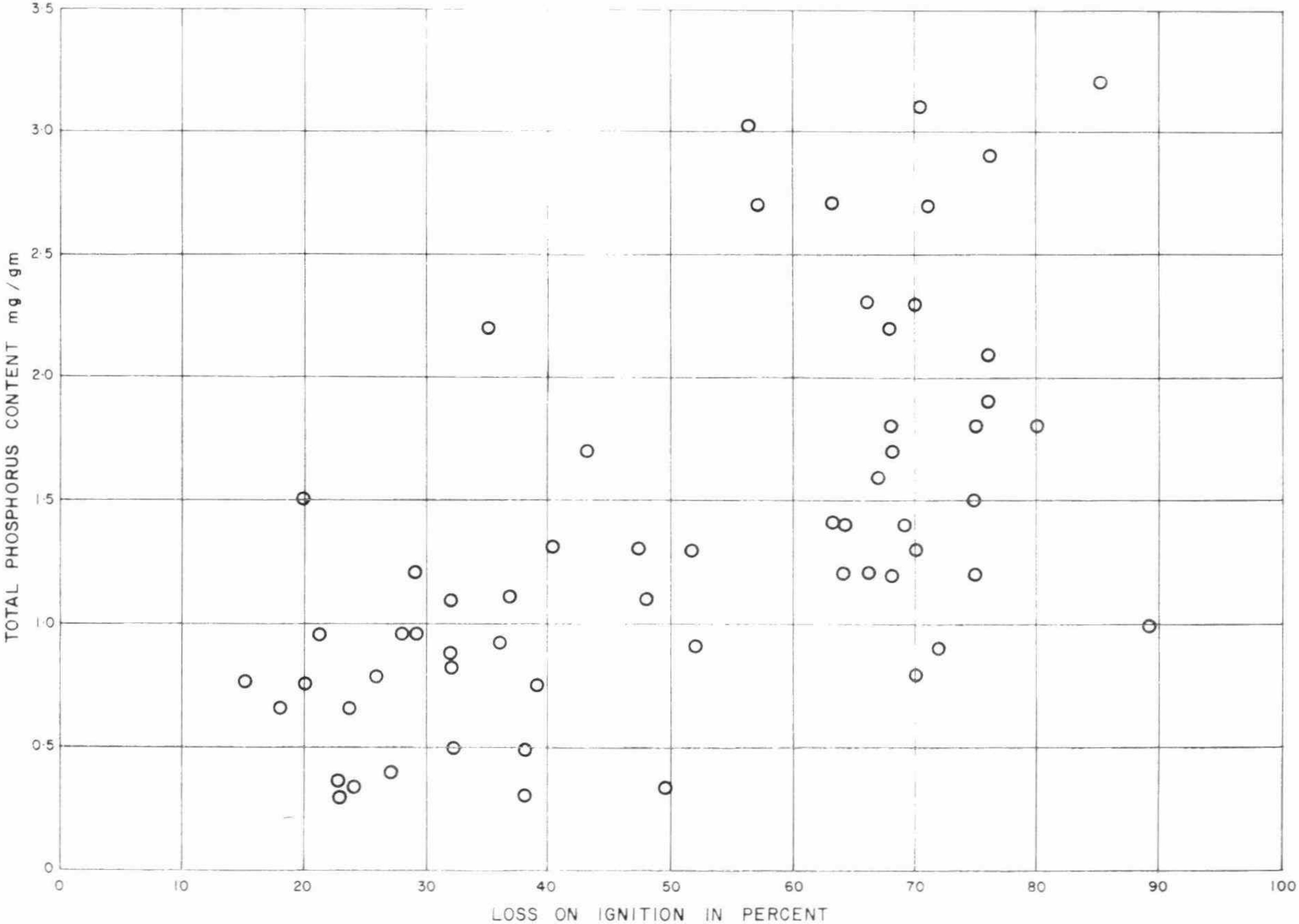

FIGURE 3. Total phosphorus content in mg/gm of plant-marl mixture versus loss on ignition in percent.

The nitrogen content appears to be entirely due to plant material (Figure 2), since high marl content gives rise to low overall nitrogen concentrations. This is due to the nitrogen in the plant being "diluted" by the inert marl.

The phosphorus concentrations (Figure 3) also indicate that there is little or no tendency for phosphorus to co-precipitate with the marl. With only two exceptions, the high phosphorus values correspond to high plant material content, although the data are more scattered than the nitrogen values. The apparent absence of carbonate-phosphorus co-precipitation is likely due to the fact that the phosphorus concentrations are low in the lake water. Effluents from chemical precipitation of phosphorus usually have phosphorus still in the mg/l range rather than the μgm/l range experienced in lake water.

It appears to be justified to use the overall concentrations of nitrogen and phosphorus and the loss on ignition values to calculate the actual concentrations in the plant material. The iron and manganese concentrations were completely random with respect to the loss on ignition values. Consequently, no conclusions can be drawn regarding co-precipitation and any conclusions regarding iron and manganese concentrations must be highly qualified unless supported by more detailed analysis.